WHAT HAPPENS TO CEMETERY HEADSTONES?

Engaging student interest in acids and bases

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A group of high school students and chaperones boarded a bus for historic Oakland Cemetery located in downtown Atlanta. Students explored the site and made observations of the gravestones, many of which were old and run-down. Upon leaving the cemetery, students—based on their interests—developed various chemistry investigations aimed at answering the same driving question: "What is causing the deterioration of Oakland Cemetery headstones?" To engage students in the concept of acids and bases, the project-based chemistry lesson described in this article incorporates the 5E learning cycle and "funds of knowledge."

Lesson planning

Funds of knowledge

To plan this chemistry lesson on acids and bases, we began by interviewing students to identify their funds of knowledge (Moll et al. 1992). According to Moll et al., employing funds of knowledge involves getting to know the "whole" student—their interests outside of school, their questions, and the cultural structures in which they live.

The science interests of the 15 students in our small focus group included the environment and pollution; other interests ranged from photography to architecture to history. Students mentioned that they enjoyed their elective classes more than their required courses because topics covered what they "wanted to know" and not what they "had to learn." Students also said they wanted to conduct their own research, and not just do laboratory experiments from the book. The information gathered from this focus group was used to develop the lesson.

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5E learning cycle with PBS

Project-based science (PBS) provides an ideal teaching strategy for incorporating funds of knowledge, allowing lessons to be designed around student interest and questions. In PBS, learning is organized around case studies, problems, projects, or questions. Five defining features of a PBS lesson include

- an authentic context that remains central during the lesson,
- a challenging or driving question,
- student involvement in designing a constructive investigative activity,
- student autonomy in decision making, and
- realistic products or presentations (Thomas 2000).

FIGURE 1

Acid and base lesson plan.

Investigating deterioration at Oakland Cemetery

Subject: General chemistry **Time frame:** Nine 50-minute periods

Preteaching plan

Specific lesson outcomes (physical science concepts):	Processes for students:	Lesson materials:	Lab materials:
• Rate of chemical reactions • Properties of solutions and nature of acids and bases • Law of conservation of matter determines chemical composition in compounds and chemical reactions **National Science Education Standards (NRC 1996):** • Science as inquiry (p. 173) • Physical science (p. 176) • Science in personal and social perspectives (p. 193)	• Observe • Hypothesize • Predict • Infer • Classify • Measure • Create • Experiment	Acid wear article, notes on acid theory, PowerPoint on solutions, notes on pH	Wood; bronze; iron; granite; marble; limestone; sandstone; 0.5, 1, and 3 M sulfuric acid; 0.5, 1, and 3 M nitric acid; water; pH paper; balance

Safety: Standard lab safety precautions include wearing goggles, gloves, and working with standard glassware lab equipment. Teacher mixes nitric and sulfuric acid concentrations (0.5, 1, and 3M) prior to the lab and dispenses in small containers using plastic disposable pipettes. Safety is enhanced if students use only a few drops of the acid solutions, dispensed from plastic dropping bottles. CAUTION

Teaching plan

Time	Performance
Day 1 (all day)	*Engage:* Students perform skit to introduce the topic and discuss prior knowledge about chemical reactions. Students take a field trip to Oakland Cemetery.
Days 2–3	*Explore:* Students work in small collaborative groups to design and conduct an investigation related to the essential question—What is causing the deterioration of Oakland Cemetery headstones?—with minimal teacher assistance. When appropriate, short direct instruction is used to facilitate learning.

To design this lesson plan, the 5E (engage, explore, explain, elaborate, and evaluate) learning cycle model was modified to incorporate the five defining features of PBS. Figure 1 presents a summary lesson plan.

Engaging students in an authentic task

The first phase of the lesson included a field trip to Oakland Cemetery, which served to introduce the driving question: "What is causing the deterioration of Oakland Cemetery headstones?" A skit was performed when students first arrived at the cemetery, which was cowritten and executed by a group of students with an interest in theater (see "On the web").

During a short discussion following the skit, students expressed some initial thoughts about deteriorating headstones—demonstrating their prior knowledge. The cemetery's head of restoration then facilitated a short question-and-answer session about caring for and respecting the headstones, statues, and fences. Students were sent on a mission to explore the cemetery and were encouraged to treat the site with respect, advised about safety issues—such as the dangers of leaning on possibly unstable headstones, or running through unfamiliar terrain—and supervised at all times. They gathered information about the history and land use of the cemetery over time, the kinds of materials used at the site, and the environment of the surrounding area. Before leaving the cemetery, students were encouraged to discuss their observations and any clues gathered that they thought contributed to those observations.

The engage phase made an explicit connection between scientific concepts and the authentic question being studied, which helped keep students focused on learning outcomes. During the discussion, students mentioned pollution or acid rain; however, a fundamental understanding of the chemistry of acids and bases—the goal of the lesson—was limited.

Days 4–6	*Explain:* Student groups present observations and findings to the class. Teacher facilitates a discussion on three models of acid/base theory and chemical reactions. Students explore ways to neutralize the reaction that occurred during experiments.
Days 7–8	*Elaborate:* Students are given an article on acid wear and asked to explain the process and provide suggestions for preventing tooth deterioration from acid.
Day 9	*Evaluate:* Students give presentations and take summative test.

Evaluation plan

Preassessment:
- Pretest given on Day 2

Formative assessment:
- Student participation
- Questioning students during investigation
- Whole-class discussions

Summative assessment:
- Group presentations
- Posttest given on Day 9

Observations and feedback to teacher:
- Students enjoyed the research aspect of problem solving.
- Students identified higher-level lab experiments that would investigate the many interactions at the cemetery as it related to the problem.
- Students' comfort zone was challenged with the investigative nature of the project.

Reflections:
- Students were able to gather basic information with little assistance.
- The concept of what pH is communicating needed further direct instruction.
- Identifying factors that increase rate of reaction were best discovered through experimentation.

Exploring an aspect of the driving question

Upon returning to the classroom, students—in small groups of three to four—developed a question to investigate that would provide insight when answering the driving question. Students were not being asked to answer the driving question at this time, but rather were attempting to answer a related question that would provide a piece of evidence. During this phase of the lesson, students developed questions and designed experiments with minimal assistance from the teacher.

Drawing from the discussion at the cemetery, students designed investigations that involved testing various acidic solutions on the materials found at the cemetery: wood, bronze, iron, granite, marble, limestone, and sandstone. Student questions helped to develop the next phase of the lesson (i.e., explaining). Some questions that students requested to investigate during lab time included:

- How does a marble headstone react to sulfuric (or nitric) acid present in acid rain?
- How might different acids (nitric or sulfuric) cause a different or more intense reaction in the bronze statues seen at the cemetery?
- Do the hot summer temperatures increase the rate of chemical reactions that deteriorate cemetery headstones?
- Do limestone headstones react differently than granite headstones to acid rain?
- How does the acidity (as measured by pH) of acid rain affect the reaction rate of the iron fences surrounding some cemetery plots?

Students' questions guided them through their investigations. After identifying the chemical compounds for each material, students were asked to think about acids and bases and predict what might occur during interactions with each of the materials. All groups were then challenged to write the chemical reaction to explain the results of their investigation.

While students were completing this activity, the teacher took note of the difficulties students were having and occasionally stopped the lesson to interject 10–15 minutes of direct instruction to help scaffold students' understanding. For example, most students required refresher instruction on solutions and chemical compounds. Students also had difficulty with the concept of pH and what determines whether a solution is acidic or basic. Because the instruction was directly related to students' investigations and delivered on a need-to-know basis, student engagement was high.

Explaining the outcome of student-designed investigations

Each student group presented its observations and findings to the class. Some students stated that the material they investigated fizzed or bubbled when acid was applied; others reported a lack of reaction. Figure 2 provides cemetery materials tested and results.

The class then discussed the results as a whole and searched for both patterns and a lack of patterns in the findings. Since students performed their investigations on types of materials found at the cemetery—wood, bronze, iron, granite, marble, limestone, and sandstone—there was evidence to suggest to students that some substances simply did not react with acid. Students were encouraged to look for commonalities among the materials that did and did not react.

The teacher then guided students through a conversation of the effects of varying pH levels on the materials tested. Students' findings and solutions were discussed as a class during group presentations. This information helped students to determine:

FIGURE 2

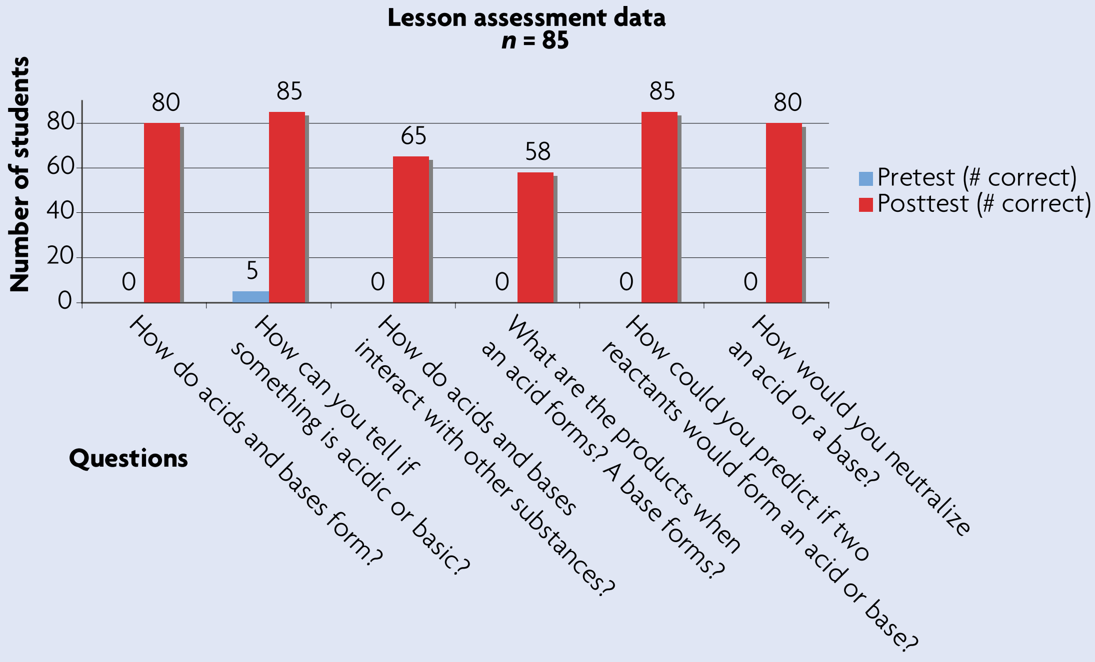
Cemetery materials tested and results.

Common name	Typical primary composition	Reacts with dilute acid? (0.5, 1, and 3 M sulfuric acid and nitric acid)
Limestone	$CaCO_3$ (calcite)	Yes (quickly fizzes)
Iron*	Fe	No**
Bronze	Cu and Sn (usually, but may contain other metals)	No
Wood	Cellulose $(C_6H_{10}O_5)_n$ and other organic compounds	No
Granite	SiO_2 (quartz), Al_2O_3 (alumina), and other minerals	No
Marble	$CaCO_3$ (calcite)	Yes (quickly fizzes)
Sandstone	SiO_2 (quartz), $KAlSi_3O_8$ (potassium feldspar), and other feldspars and minerals	No

*Nongalvanized iron (without zinc coating) was used for the test.
** Dilute acid on iron results in a darker gray color; however, students did not make this observation.

FIGURE 3

Acid and base lesson assessment data.



- which factors contributed to the formation of acid rain,
- what increased the rates of reaction between acid rain and calcium carbonate, and
- which solutions could be implemented to prevent the exposure of the materials to acid rain and thereby essentially prevent or decrease the reaction.

Elaborating and synthesizing student decisions and findings

Next, students were asked to make a connection between project information and daily life. The lesson therefore went a step further to show the acids and bases students encounter on a daily basis.

Student groups were given an article to read that focused on acid wear—a problem that occurs when teeth enamel deteriorates due to exposure to acidic beverages and food (Bakalar 2005). Using this information and the knowledge acquired from the investigation discussion, students worked to explain the process of acid wear and suggest ways to prevent the deterioration of materials caused from acid. Each student group was challenged to look at one of the following aspects of the problem:

- What might be causing the problem?
- How would teeth react to constant exposure to acids given that the major chemical compound of tooth enamel (calcium phosphate) is closely related to that of the cemetery materials (calcium carbonate)?
- What practical solutions—such as the ones developed to limit headstone exposure to acid rain—could be used to limit teeth exposure to acid in food and beverages?

Student groups met to discuss their ideas and solutions, which were then shared and discussed with the entire class.

Evaluating student answers to the driving question

By the end of the lesson, students were expected to demonstrate their understanding of the learning outcomes through a variety of assessments (i.e., small group questioning, a presentation, and a summative test). Upon completion of the lesson, most students demonstrated an advanced level of understanding by answering the following questions:

- How did the history of Oakland Cemetery affect the deterioration of headstones?
- What role does the current environment play?
- How does climate affect the conditions of the various headstones?
- What are the chemical compounds that interact at the cemetery?
- What is the chemical composition of each material tested?
- What is the chemical difference between those things that react with the acid and those that do not?

- What is meant by the term *pH*?
- How is something classified as acidic or basic in terms of hydrogen (H^+) and hydroxide (OH^-) ions?
- How would the formation of acid rain look as a chemical equation?
- What would be the chemical equation for the reaction(s) of your investigation?

Assessment and reflection

Pre- and posttest

This PBS lesson was carried out in a suburban high school that serves a diverse student population (59% White, 20% Black, 12% Hispanic, and 9% other; 19% eligible for free or reduced lunch). Eighty-five students taking 10th-grade general chemistry were given identical pre- and posttests consisting of six short-response questions. To accommodate multiple learning modalities, students were encouraged to draw diagrams and provide examples.

Students' answers were evaluated on the depth and accuracy of information provided and coded as having either basic or mastery understanding. Figure 3 (p. 33) provides a graph of the assessment results. The pretest showed that most students had a limited understanding of the lesson concepts. Posttest results revealed that 94% of students mastered the majority of lesson concepts and 68% of students mastered all lesson concepts. Compared to the more traditional acid–base units previously taught, this level of student mastery was quite high.

Student feedback

Equally important to assessment outcomes was the level of engagement demonstrated by students. Out of 85 students working in 21 small groups, only 1 group—who preferred direct instruction and notes to memorize for a test—demonstrated a negative disposition to learning by inquiry. The feedback from the majority of students included many comments about the enjoyment of taking chemistry outside the classroom.

Students also commented on how chemistry topics were made obtainable through the use of everyday concepts. Shortly after the field trip, the cemetery was struck by a tornado, which caused much devastation to the grounds and headstones. This event became the topic of discussion during class with students expressing an interest in helping to clean up the storm damage at the cemetery. This feedback suggests that this lesson was more than just an entertaining field trip and truly engaged students in learning within their community and fostering their sense of place.

Conclusion

For this PBS lesson, Oakland Cemetery remained a central focus and provided an authentic driving question. Students were given the flexibility to design and make decisions throughout their inquiry investigation, and the presentations provided realistic solutions for preserving cemetery headstones. Increases in both student engagement and understanding of the concepts in this PBS lesson could be due to several factors.

We believe that incorporating the funds of knowledge perspective and including student interests, community involvement, and student questions played an important role in the positive learning experiences of students. A funds of knowledge perspective allowed the teacher to connect science to students' interests, and invited students to be part of curriculum development. After this learning experience, students frequently provided curriculum suggestions, which to us demonstrates that incorporating student ideas has a sustained impact on their ownership of science learning. ■

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On the web

Acid and base PH tutorial: *www.chem.ubc.ca/courseware/pH*

Acid–base reactions: *www.sasked.gov.sk.ca/branches/elearning/tsl/resources/subject_area/science/chem_30_resources/lesson_8/default.shtml*

Acids, bases, and pH: *http://web.jjay.cuny.edu/%7Eacarpi/NSC/7-ph.htm*

Student skit: *www.nsta.org/highschool/connections.aspx*

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