Teaching Chemistry Through Inquiry

THE PEANUT LAB

In this case study, we will observe Teresa Gerchman, a veteran teacher of 17 years, as she leads her 10th-grade students through a lesson on calculating energy and caloric content. Teresa teaches Advanced Placement and college preparatory chemistry at Spencerport High School. The class in this case study contains 21 regular education students and 3 special education students. A teacher aide assists Mrs. Gerchman 2–3 days a week by providing resource help in the room to the three special education students.

After participating in several professional development workshops on inquiry 5 years ago, Teresa shifted her instructional methodology to an inquiry-based approach. She now incorporates inquiry into all phases of her instruction. Teresa is also the head of the science department and places a high emphasis on inquiry-based instruction throughout the department, which she reinforces by modeling scientific inquiry in her classroom. Teresa’s chemistry labs usually involve students writing their own investigations, designing procedures, and choosing what kind of data to collect. Over the course of the school year, students will plan and design 10–15 of their chemistry labs. Her chemistry course culminates with students designing and carrying out a full research project in May. This lab focuses on decision making and determining the amount of energy stored (caloric content) in a peanut. Although many high school chemistry teachers undoubtedly are familiar with the infamous “peanut lab,” during this experience, students, not the teacher or the lab manual, decide how to plan the procedure, what materials to use, and how data will be collected and represented.
This “peanut investigation” is divided into 4 days; the odd days, 1 and 3, each comprise a 90-minute, double period. The even days, 2 and 4, are single 45-minute periods. During Day 1, students review the previous day’s lesson and the joule concept. They are also introduced to a teacher-initiated inquiry, the peanut lab, in which they plan and carry out the lab procedures, as well as record and analyze the results based on a question posed by the teacher. Day 2 involves a brief review lecture, an introduction to new material related to heat energy, and the extended, student-initiated inquiry lab in which students design a lab based on questions they raise. On Day 3, students carry out their investigation, organize their evidence and data, and make graphs and charts to communicate the results. To communicate the results and conclusions of their investigations, each group is required to make a 5-minute oral presentation using either a trifold poster board or a PowerPoint presentation on Day 4.

The peanut investigation aligns to the National Science Education Standards (NRC, 1996) for grades 9–12, as quoted below.

**Science as Inquiry Standard**

Students will

- Identify questions and concepts that guide a scientific investigation. (p. 175)
- Design and conduct a scientific investigation. (p. 175)
- Use technology and mathematics to improve investigations and communications. (p. 175)
- Formulate scientific explanations and models using logic and evidence. (p. 175)
- Communicate and defend a scientific argument. (p. 176)

**Physical Science Content Standard**

As a result of activities, all students should develop an understanding [that]

- Chemical reactions may release or consume energy. (p. 179)

**Life Science Content Standard**

As a result of activities, all students should develop an understanding [that]

- The chemical bonds of food molecules contain energy. (p. 186)

**Day 1**

Mrs. G., as her students call her, starts the class by reviewing the previous day’s homework. “Which unit is used to express the amount of energy absorbed or released during a chemical reaction?” she asks.

“A joule,” one student responds.

“If two systems at different temperatures have contact with each other, how will the heat flow from one object to another?” is the follow-up question.

Another student answers, “From high to cold temperatures.”

One of the students who’s also on the football team then asks, “If placing a cold pack on a swelled ankle feels cold, how is the heat moving from the ankle to the cold pack? Isn’t it the other way around?”
Teresa thinks to herself, “This presents one of those teachable moments to apply the laws of thermodynamics beyond the classroom and into the student’s real life.” After a brief explanation on the cold pack question, she moves on and poses two questions as a “warm-up” quiz.

How much heat is needed to melt 50 grams of ice?

and

How much heat is needed to vaporize 10 grams of water?

Mrs. G. suggests that students use their notes from the previous day’s class and their Chemistry Reference Tables (The University of the State of New York. (2002) to apply the appropriate formula to answer the questions.

While students work on the problems individually, Teresa and the special education aide walk about the room, assisting those students who need help. The students are then told to “pair and share” their solutions with a partner. While Teresa walks about the room, she chooses several students to come up to the board and share their solutions with the class. The teacher and students discuss the various ways to solve the problem. The class comes to agreement on the correct solution.

How much heat is needed to melt 50 grams of ice?

Heat of fusion: \( MHf = q = 50 \text{ grams} \times 334 \text{ J/g} = 16,700 \text{ joules or 16.7 KJ} \)

How much heat is needed to vaporize 10 grams of water?

Heat of vaporization: \( MHv = q = 10 \text{ grams} \times 2,260 \text{ J/g} = 22,600 \text{ joules or 22.6 KJ} \)

As part of the prelab discussion, Teresa introduces the lab by saying:

Energy that is produced when plants go through photosynthesis is stored in the leaves, roots, and stem. We eat food to get that stored energy. When food is “burned” during the process of digestion, the energy is released as heat energy in our bodies. The amount of energy is measured in calories. One calorie is equivalent to 4.2 joules. The amount of energy released by the food can be calculated, and the amount of energy stored in the food determined.

In this lab, you are to determine how much stored energy, in joules, a peanut has. You all have regular laboratory equipment available for your use as well as peanuts and matches. Your job is to write out the equation to calculate the heat energy released by the peanut as it burns. Identify what variables you will need to measure in the lab, and then write a safe procedure to determine the amount of heat energy released by the peanut as it burns. Include a drawing of how your lab equipment will be set up. For today’s lab, you are going to design a way to determine the amount of energy in a peanut.

Teresa then tells students to take out their chemistry lab journals and record all their information in their notebooks.

After the students pair up, each group begins to work on brainstorming the design of the lab.
While students are doing their work, the teacher takes attendance and returns the previous day’s homework assignment. After 15 minutes, Teresa asks several groups to come up to the front of the class and share their lab designs with the class.

In Model #1, Jessica and Kara thought about using a Bunsen burner to heat the water in a beaker, allowing the steam from the water to heat the peanut being held above the beaker. They thought they would take the temperature of the peanut before and after heating and then calculate the change. But they weren’t quite sure how they were going to take the temperature of the peanut.

In Model #2, Samantha and Josh thought they would heat the peanut with a Bunsen burner and then place the peanut in a beaker of water and see how many degrees the water temperature changed.

In Model #3, Sade and Gina proposed using a match to ignite the peanut and then using tongs to hold the peanut under the beaker of water to determine how much the temperature rose. They thought they would take the temperature of the water before and after heating to calculate the change in temperature.

During the final discussion of the three proposals, students agree that Model #3 is the most appropriate way to do the lab; however, Gina adds that not all the energy released from burning the peanut is absorbed by the water—some energy is lost to the air, and some is lost through the tongs.

Mrs. G. then asks, “Would the tongs absorb some of the heat?”

Gina answers, “Yes. We should use something thin like aluminum wire or a pin rather than those tong things.”
As the students write up their lab procedures in their science journals, Teresa reminds them to identify safety concerns. Commercially produced labs usually address safety concerns, but because students are writing their own procedures, including safe practices reinforces safety and makes students more accountable for their own behavior in the lab.

A typical peanut lab looks like this:

**Title/Question:** How much energy is in a peanut?

**Purpose:** To measure the amount of heat energy released by a peanut as it burns.

**Materials:** Ring stand, ring clamp, wire mesh pad, graduated cylinder, 500-mL beaker, peanut, pin or wire, cork, water, matches, thermometer, electronic or triple-beam balance, and goggles.

**Procedure:**
1. Assemble a ring stand, ring clamp, and wire mesh pad.
2. Using a graduated cylinder, measure 100 mL of water and place it in a 500-mL beaker. Place the beaker of water on the ring clamp.
3. Using a thermometer, determine the temperature of the water in the beaker. Record the temperature in the science journal.
4. Assemble peanut holder by placing a pin, pointed side up, in a small cork stopper. Place a peanut on the pointed end of the pin. Position the peanut and holder under the beaker and ring clamp.
5. Using a match, light the peanut and allow it to burn completely.
6. After the peanut burns itself out, determine the temperature of the water after heating. Record the temperature in the science journal.

**Safety procedures:** Wear goggles, and be careful when using matches.

**Data:** Temperature of water before heating = 

Temperature of water after heating = 

Change in temperature = 

When a group’s write-up for the lab is complete, the teacher approves and signs off on the lab by placing a “smiley face” on the paper. While Mrs. G. circulates around the class placing approval smiley faces on papers, Rob and Dave ask, “Should we use a whole peanut or just a half?”

Teresa responds, “I don’t know. Will it make a difference? We’ll have to find out later.” She purposely doesn’t answer the students’ question because she knows the class will answer that question at the end of the lab.

After the lab, students calculate the amount of joules of heat energy released by the peanut. Sade and Gina use the formula \( q = mC\Delta T \) to determine the amount of energy; where \( q \) equals the heat in Joules, \( m \) equals the mass of water, \( C \) equals the specific
heat capacity, and $\Delta T$ equals the change in temperature. Because the temperature of Sade’s and Gina’s water increased from 20 to 24 degrees and the specific heat of water equals 4.18 J/g K, their formula for the amount of heat is $100 \times 4.18 \times 4 = 1,672$ joules or 1.7 kilojoules. (In the investigation, students used 100 mL of water. Because the density of water equals 1 gm/mL, 1 mL of water weights 1 g. Following the formula, 100 mL of water weighs 100 g.)

As the students share their lab results with the class, Mrs. G. poses the question, “Was number of joules the same for each group? Why or why not?”

While some students report as few as 1,254 joules, others report as many as 2,926 joules. One student asks, “Why is there such a variation in the number of joules?”

Teresa responds, “Did different students use different-sized peanuts?”

“Yeah, I think so,” answers Michael.

“Well, then,” she continues, “do larger peanuts have more energy than smaller ones?” At that time, she uses the analogy comparing a regular-size and large-size Snickers candy bar for calorie content. She encourages several students to prove this statement by determining the number of joules per gram during the extension or “going further” stage of the lab.

A student then asks, “Should the amount of energy released equal the amount of heat absorbed by the water?”

Mrs. G. says, “That’s a good question. What would you expect? Should it? Let’s look at your data and see if we can find the answer.” The lab closes with a discussion about how the amount of heat stored compares to the amount of heat released and measured by the change in temperature. Students then add the analysis section to the lab journal. After the analysis section, Teresa has students summarize their lab by suggesting ways, if any, to improve it.

**Day 2**

On Day 2, Teresa begins the period with a presentation in which students solidify their understanding of a joule. By providing examples and referring to the previous day’s lab, students construct their knowledge of the heat concept and calculating joules. Among the question presented to students is “What is the equation for determining the amount of heat energy, in joules, that is involved in a reaction?” Several problems are presented, such as “How many joules are required to heat 150 grams of water from 30°C to 40°C?” Or “If 4 grams of water is vaporized at 100°C, how much heat energy is used?” Students are given problems in which they convert joules to kilojoules and integrate graphing skills by drawing a heating curve to show the changes that take place when you heat a 20 gram sample of ice at -5°C to a water vapor at 110°C. During the presentation, Teresa also reviews the formulas for the heat of vaporization and the heat of fusion.

Students use the data and evidence from their previous lab to design their own new investigation. In this student-initiated inquiry, individuals choose their own question to investigate, design and carry out the procedures, and collect and analyze the results. To initiate some ideas, Teresa places a can of mixed nuts on the front lab table. After a brief brainstorming session, students come up with the following questions to investigate:
Which nuts contain the most joules? Hazelnuts, chestnuts, cashews, peanuts, pecans, walnuts, or Brazil nuts? (Anticipating this question and wanting to add a little humor to the class, Teresa shows a film clip from the movie *Best in Show* in which one dog owner describes his ability to name different types of nuts.)

- Do regular peanuts produce more heat than dry-roasted peanuts?
- What is the amount of joules given off by a mini marshmallow? A large marshmallow?
- Do potato chips or Doritos provide more energy?

Finally, Rob and Dave, who asked in the first lab whether they should use a whole or half peanut, decide to use different-size peanuts and determine the amount of joules per gram. Taking the mass of various sized peanuts will allow them to calculate the amount of joules per gram.

As the students design their extension or follow-up labs, Mrs. G. passes out the rubric for grading their investigations.

**Day 3**

The students are eager to get started on their investigations. As soon as the period begins, students move to the chemistry lab and start getting their materials together to carry out their investigations.

In a corner of the lab, one large group of students is determining the amount of heat given off by different kinds of nuts. The group divides into four subgroups, each taking a different type of nut to test.

In another section of the lab, Rick and Linda are testing regular peanuts versus dry-roasted peanuts, while Sandy and Sharon are measuring the amount of joules given off by a mini marshmallow versus a large marshmallow. Tim and Bernie's lab proves to be a bit troublesome as they try to test whether potato chips or Doritos corn chips provide more heat energy. They find that their samples burn up too soon to measure any substantial change in temperature.

Rob and Dave's interest from Day 1 focuses on whether size of the nut makes any difference. They test whole and half peanuts to determine the amount of joules per gram.

At the end of the first half of the period, each group has enough information to answer its question, so students begin to plan their presentations. Teresa informs the students that their investigations and presentations will be graded using the rubric handed out on the first day. Each group is required to make a 5-minute oral presentation using either a trifold poster board or a PowerPoint presentation to convey the results and conclusions of their peanut investigations. The class spends the rest of the period preparing their presentations.

**Day 4**

On this, the final day of the lab, each group comes up to the front of the class to communicate its investigation findings. At the end of each presentation, Teresa poses the question, "If you were to improve your investigation, what would you change?"

After all the groups make their presentations, students are given a test to assess their understanding of heat and calories.
AN INTERVIEW WITH TERESA GERCHMAN

How would you describe your approach to learning?

Teresa: I keep my students actively engaged. To do that, I lecture as little as possible and instead give them opportunities to come up with their own ideas that are practical and relevant to their daily lives. Very rarely do I give them 45 minutes of note taking. When I do lecture, I limit it to shorter periods to reinforce a topic that we are studying. When I started teaching, I used a typical lecture approach because that’s the way I was taught. But as time went on, I saw more practical applications develop when students came up with the examples on their own. Students develop more meaning through their investigations than when I ramble on and on about some law. Now I get very few complaints when students have to take notes because they know it won’t be all period long and that the information will apply to their questions and experiments.

In this class, you have both regular and special education students. To an outside observer, it would be difficult to tell which of the students are special education. Does learning through inquiry in a high school science classroom seem to blur the distinctions between students with learning disabilities and those without?

I believe so, because what I’m asking students to do is think. I’m not asking them to give back rote information. Having a learning disability often means that some students just learn in a different style. It does not mean that they cannot learn or are not smart. When you stop asking students to do something in a traditional way and instead use their abilities to raise questions and inquire, students with learning disabilities are placed on an equal footing with other students. I find that students with learning disabilities work better in an inquiry environment because special education students tend to think out of the box more easily. Experience tells me that kids who have the most trouble with inquiry are those at the top end of the spectrum. They are used to doing exactly what you tell them to do and are ready to give you back anything you tell them. So when you ask high-ability students to come up with their own ideas, it often “pushes” their comfort zone. There are always some students with learning disabilities who need special accommodations, but teaming students together in cooperative groups often compensates for any disability. In this class, I have a wonderful special education aide I work with. She is a firm believer in inquiry and is an active part of the learning process for both regular and special education students. So I think the students with special needs like inquiry because in inquiry classrooms, all students are engaged in the learning and are experiencing success. In this class, the special education aide interacts with all students, so it is difficult to identify students with special needs from those without. Working together is a true cooperative teaching model. The special education aide is especially helpful in thinking of ways to differentiate the instruction so we are certain to meet the needs of all students in the classroom.

How does inquiry help you differentiate instruction to meet the needs of all students in your class?

To begin with, it is truly an ideal individualized learning environment. What procedures students design and carry out in the lab varies based on their choices.
Some students develop labs with great minute, step-by-step details, whereas other students may keep their investigation simple and to the point. And that’s fine, since inquiry-based instruction lends itself to self-selection and individualized learning.

**In your classroom, you emphasize students designing their own investigations and labs. Do you think students like this approach?**

At first, I sometimes think they hate it because it forces them to think, but later they come to understand that they are being encouraged to think in science and they come to enjoy the labs. They don’t dread coming to class, so my average daily attendance rate is high. I also think students have a greater appreciation for what’s going on in the lab and not just going through the steps. That’s important to me.

In one lab, we did an identification of acids and bases. I told my students, “When you come in tomorrow, there will be five clear liquids on the desk. You need to identify which ones are acids and which ones are bases.” And that was it. That was all the direction I gave them. I didn’t even give them a lab sheet. So the night before the lab, they had to go through their chemistry reference tables and determine which chemical indicators to use to distinguish between acids and bases. They had to decide which indicator they were going to use, test each sample, and later classify the acids and bases according to strength. Oh, by the way, I told them they could use pH paper only to test their final results at the end of the lab. When they came in the lab the next day, I had vials of methyl orange, bromthymol blue, phenolphthalein, and thymol blue available. I also had some metals available to test for acids. The students then used the information they found to test each liquid and sequence them from the strongest acid to strongest base. Actually, they classified each liquid as a strong acid, a weak acid, being neutral, a weak base, or a strong base. The following day, we discussed what indicators were used in the investigation and how they are used in chemistry, along with the general properties of acids and bases. That led us to an understanding of pH. The students then brought in common household liquids from home, and we tested each one for pH and general strength. That, in turn, led to a bulletin board display of all the liquids we tested, along with their identification as either an acid or a base. It was an interesting display that students were proud of. On the final exam, there was a question for which students had to determine, given two liquids, which was an acid and which was a base. They remembered the lab and completed that question quite easily.

**Do some students prefer to have the lab given to them?**

They would at the beginning of the school year, but later they become accustomed to the inquiry style and really do enjoy learning this way. As I said earlier, it’s the highest-ability students who I find have the most difficulty adjusting to inquiry. They prefer to memorize and give back the information. I think they have been conditioned to a recitation style most of their lives, and inquiry is a new and different type of learning. High-ability students are very good with a traditional model of teaching because that is what they are accustomed to. Later, as the transition occurs, they become quite comfortable with inquiry and realize how it encourages their thinking skills. But it takes nearly a year for the transition to occur.
In the beginning of the peanut lab, students were designing different models to test. There were two very unusual models presented. Does it surprise you to see what students are thinking about?

I don’t think there is a specific process for modifying a lab; the process is different for different labs. I generally start with the question, “How can I get students to design this lab on their own?” For example, I have a traditional lab on the rate of chemical reactions. It’s a standard lab, the iodine clock lab, I’m sure a lot of high school chemistry teachers use. But to make it more inquiry oriented, I pose the following task to my students: Choose a factor you believe will affect the rate of reaction. Write a hypothesis statement regarding what factor you wish to test and what you believe the effect will be on the rate. Next, design and carry out an investigation to test your hypothesis. This task is clear enough that I don’t have to provide a list of the materials to use or the procedures to follow. I believe students can determine this information on their own. Some may need a bit of prompting, while others determine it on their own. Some groups choose heating the reaction, others choose varying the concentration or stirring, while some choose adding a catalyst. In this case, I can expect about four different experiments going on at the same time. Toward the end of the period, I’ll get all of the heat groups together in one area to come up with some general conclusions about the effect heating has on the rate of reaction. The same goes for the other groups. This way, all the groups collaborate with each other and share their results.

None of my labs includes data tables. I want students to determine what data they have to collect and how they need to organize the information on a chart or table. This helps students take more responsibility for the lab and make decisions on their own. Also, I always have students write their own hypothesis. Then I ask, “How can you test your hypothesis?” By having students write their hypothesis, they are naturally led to the next step of writing the procedure to test their hypothesis.

What did your labs look like 10 years ago? What do they look like now?

Back then, I gave students the question to investigate, the materials that they will use, the steps to follow, an illustration of what the setup should look like, and so on. I even provided them with a table to organize their data and a grid to plot the results. Basically, the entire lab was laid out in front of them. Then, of course, there was a follow-up question to help them analyze their data and draw conclusions. The lab might have been three or four pages long. Now most of my inquiry chemistry labs are one sheet long. It certainly saves on paper!

Are you ever surprised by the ways high school students design their own chemistry labs?

If you remember, in the peanut lab there were two groups of students who had bizarre ideas for determining ways to calculate the amount of energy from the nut. One wanted to heat the peanut and put it in water and measure the temperature change; the other wanted to heat the peanut from the steam of boiling water. Those ideas stressed the need to walk about the classroom and interact with the groups. We have to know what they are thinking about. Sometimes, what the teacher is saying may be entirely different from what students are thinking about. I’m not always sure that the things they say will work actually do, but I often say, “Try it, and see what
happens.” We think students know what we are talking about, but sometimes they don’t. That’s the power of inquiry—students have to brainstorm their ideas and test them against the class and the teacher.

*At the high school level, especially in chemistry, there seems to be an enormous amount of content you need to present throughout the school year. How do you manage to integrate an inquiry-based approach knowing inquiry takes more classroom time?*

In the past, I would start a unit by presenting the topic through a lecture/discussion mode, then use inquiry as a way for students to design an experiment around the topic or concept. Back then, I would use a 40-minute period to teach the concept and then an 80-minute lab to apply the concept through an investigation. Now I prefer to use inquiry as a way to introduce concepts and then support the evidence we discovered from the investigation with formulas and background information. I make the introductory inquiry lesson part of a 40-minute period and then use the explanation portion in a follow-up 40-minute period. That saves me some time. I also find that with inquiry, the students “own” the knowledge, so I have to spend less time reviewing at the end of the unit.

Chemistry teachers who use inquiry have to be very efficient with their time. That means starting on time and using the entire class for instruction. I rarely provide time in class for students to do homework or write up their lab. That can be done at home. Classroom time is too precious to use for doing homework. Plus, a lot of the planning and design of the investigation can be done on their own time, not in class. I find that the more we use inquiry, the less often I have to use classroom time for the design phase of the investigation. After a few months, they know what to expect for labs, know how to write a hypothesis, and can design the procedures to test their hypothesis.

**QUESTIONS FOR REFLECTION**

1. How can inquiry help increase differentiation of instruction in a high school science classroom?
2. How can an inquiry-based classroom be a model for inclusion?
3. How can using inquiry help students gain a deeper understanding of the core concept?