Why Lecture Demonstrations Are 'Exocharmic' For Both Students And Their Instructors

Perspective

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A theoretical model is proposed to explain why lecture demonstrations are often popular among both students and their instructors. This model provides hints about selecting demonstrations that are most likely to enhance the learning of chemistry. It also suggests ways in which demonstrations can be used more effectively.

Introduction

There are many reasons for doing lecture demonstrations.

- They are fun to do.
- Students like them.
- They grab the students' attention.
- They provide breaks that help students recover from the deluge of information in a typical class.
- They provide concrete examples of abstract concepts.
- Most importantly, they can teach chemistry.

Demonstrations are so attractive they are sometimes done under conditions where neither the students nor the instructors are adequately protected against injury. In an earlier paper we collected examples of accidents and near accidents that might remind chemists of the need to pay more attention to safety when doing demonstrations, hopefully without frightening them away from demonstrations.[1]

Some demonstrations are so much fun for both the students and their instructors that the term *exocharmic* has been used to describe these demonstrations that are so inherently fascinating they "exude charm".[2] The thermite reaction might be an example of an exocharmic demonstration.

$$Fe_2O_3(s) + 2\ Al(s)\ ?\quad Al_2O_3(s) + 2\ Fe(l)$$

In a lecture manual developed for use at Purdue University, we describe various ways in which this popular demonstration can be used.[3] We argue that it can be used as the basis for discussions of the chemistry of the elements; to demonstrate what we mean by the term *exothermic*; to convince students that aluminum is not 'inert', regardless of their experience with sandwiches wrapped in aluminium foil; or to help students develop an appreciation of what we mean when say that a reaction gives off approximately 800 kJ/mol.

This paper is based on the assumption that none of these uses satisfactorily explains the enormous attraction that demonstrations of the thermite reaction have for both students and their instructors. Furthermore, it assumes that it might be useful to understand the fascination of 'exocharmic' demonstrations such as the thermite reaction, so that demonstrations can be used more effectively to teach chemistry. It therefore proposes a model based on a theory of motivation, which assumes that these demonstrations fall into the category of phenomena known as *discrepant events*.

A Theory Of Motivation

When I was a student, the most hated words in the English language were 'intuitively obvious' because they were invariably used to describe things that were never obvious to me. When I became a teacher, the most hated words became: "Is this going to be on the exam?" Often, but not always, students' use of this phrase stems from their questioning the value of material we ask them to learn because they don't think it is important. We've seen this behavior with students of all ages, from elementary school through the final stages of graduate work. It is frequently a sign of the instructor's failure to motivate the students to *want to learn*.

Motivation is a complex topic.[4] One aspect of motivation, however, can be understood in terms of the theory of optimal arousal.[5] This theory assumes that we try to attain a state in which we experience *some* arousal of our senses — not too little, nor too much. At times, we devote considerable effort to raising our arousal level by reading exciting stories; by going to scary movies; by riding roller-coasters; and so on. Other times, we escape situations where too much is happening to seek peace and quiet. It isn't just the frequency and intensity of the input our senses receive that determines arousal. The *content* of this sensory input is also important. Consider what would happen if you put down that fascinating document on household contents insurance and picked up a novel you found interesting. There would be no change in the frequency or intensity of the input your senses would receive. (No more light would reach your eyes, for example.) But it is likely that there would be a change in your level of arousal.

What makes us respond to an object or event isn't the physical input of our senses as such, but a difference between what we experience and what we expect. In other words, we respond to situations that have an element of *surprise*.

We tend to like mild surprises, not severe ones. If there is no surprise, there is too little arousal and we feel bored. If there is too much surprise, we feel shocked and disoriented. With due apologies to the author of the story of Goldilocks and the Three Bears, this theory assumes that we avoid extremes of either too much or too little surprise, and tend toward an intermediate stage in which the amount of surprise is 'just right.'

There is abundant evidence that we become habituated to events that occur in a regular schedule to the point that we ignore them. (We no longer respond when the event occurs.) One of the most common occurrences of this phenomenon in the classroom involves rhetorical questions. It has been shown that many teachers fail to give students enough time to develop answers to questions they ask.[6] The students soon become habituated to the teacher's tendency to ask questions for which answers aren't expected — rhetorical questions — and from that point on, they don't even notice that questions are asked.

Educators have long recognized the role of the unexpected in motivating students.[7] Curiosity, for example, has been shown to be an important component of learning, particularly among children.[8] But what is curiosity if not a drive to investigate and understand situations that evoke surprise? Individuals in all age groups show a marked preference for objects or situations that are novel; that have an element of surprise or incongruity; that generate uncertainty. One of the simplest ways of introducing surprise into the classroom — and therefore take advantage of students' natural curiosity — is through a phenomenon known as a *discrepant event*.

Discrepant Events

Discrepant events have two characteristic properties: They are contrary to what we intuitively expect and they are events we experience for ourselves. Being told something that is counterintuitive doesn't constitute a discrepant event because we can resolve the conflict between what we hear and what we expect by questioning the validity of what we are told. This is harder to do when we observe the event ourselves.

The thermite reaction can be a discrepant event. Students know that chemical reactions give off energy. (They might even know how to calculate the amount of energy liberated.) But the magnitude of the energy given off in this demonstration and the speed with which it is liberated are counterintuitive. Even those of us who should know better are still surprised by the vigor with which two seemingly 'inert' solids react.

Young children are often surprised by iodine clock reactions[9] when they first encounter them because of the speed with which the solution turns from colorless to deep blue. The 'Old Nassau' demonstration[9] — in which the solution first turns orange and then black — is even more surprising because students don't expect the contents of a beaker to change color twice. Oscillating clock reactions,[10] however, are better examples of discrepant events. Regardless of the extent to which students have been exposed to the concepts of reversible reactions, equilibria, kinetics, thermodynamics and so on, there is nothing in their prior experience that prepares them for a reaction that cycles between states in which the solution is colorless, then gold, and then blue.

Implications Of This Model Of Exocharmic Demonstrations

The notion that some of the fascination of lecture demonstrations results from the fact that they may be discrepant events has an important implication: Demonstrations don't have to be spectacular to be effective. They should, however, contain an element of the unexpected.

Let me offer an example, from my own experience. When I took chemistry for the first time, I was told that equal volumes of different gases contained the same number of particles. Until I took physics, this was the most absurd thing I had heard a teacher claim to be true. I knew that gases contained empty space, but I seriously underestimated the fraction of the space that is empty. It therefore seemed reasonable to expect that equal numbers of gas particles of different size would occupy different amounts of space. I now know I was in good company; Dalton rejected Gay-Lussac's data on combining volumes for the same reason. To me, and to many of my contemporaries, Avogadro's hypothesis was just as counterintuitive as it was to John Dalton.

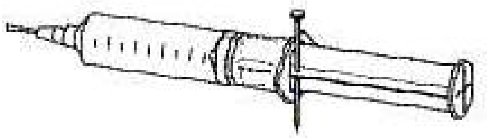

Figure 1

I am reasonably confident that I could have stated Avogadro's hypothesis, if asked to do so on an exam. I am equally confident that I couldn't have used Avogadro's hypothesis to solve a problem because I didn't really believe it to be true.

About 15 years ago, I learned a lecture demonstration that provides a discrepant event that confronts the intuitive model of gases I brought to my first chemistry course.[11] Start with a plastic 50-mL Leur-lok syringe, a syringe cap, and a 10-penny nail. Pull the plunger out of the barrel until the volume reads 50 mL. Now drill a small hole through one of the veins of the plunger into which the nail can be inserted, as shown in Figure 1.

gas	Weight of 50 ml of gas	Number of particles In 50 ml of gas
H_2	0.005 g	1×10^{21}
N_2	0.055 g	1.2×10^{21}
O_2	0.061 g	1.2×10^{21}
Ar	0.081 g	1.2×10^{21}
CO_2	0.088 g	1.2×10^{21}
C_4H_{10}	0.111 g	1.15×10^{21}
CCl_2F_2	0.228 g	1.14×10^{21}

Table 1

Push in the plunger until no gas remains in the syringe, seal the syringe with a syringe cap, pull the plunger back out of the barrel of the syringe, insert the nail into the hole, and weigh the 'empty' syringe to the nearest 0.001 grams with an analytical balance. Fill the syringe with different gases[*] and determine the weight of 50 mL of each gas. Now use the molar mass of each gas to calculate the number of gas particles in each sample.

Typical data obtained with this apparatus are given in Table 1. Within experimental error, the number of gas particles in each sample is the same. It might still seem strange that equal volumes of different gases contain the same number of particles, but it is no longer possible to avoid this conclusion. Although this demonstration isn't as spectacular as the thermite reaction, or one of the oscillating clocks, it can still be exocharmic because it contains an element of surprise for many students.

Some demonstrations, such as the hydrogen whistle,[12] are such excellent sources of surprise that

[*] A simple way to handle gases for lecture demonstrations starts with a 1 or 2 inch length of ¾-inch diameter plastic tube. Plug one end of the tube with a rubber septum and secure the septum to the tube with copper wire. Fill a balloon with the appropriate gas from a gas cylinder and insert the open end of the plastic tube into the mouth of the balloon. A sample of the gas can now be collected with a syringe by inserting the syringe needle through the rubber septum

nothing has to be done to enhance their status as discrepant events. The hydrogen whistle is based on the apparatus in Figure 2, which consists of a pair of metal funnels welded together so that there is a small hole at the top and a somewhat larger hole in the bottom. The apparatus is filled with H_2, the hole at the top is plugged with a match, and a rubber stopper is used to close the hole at the bottom. The lights are then dimmed, the stopper and match are removed, and the match is used to ignite the H_2 that escapes through the hole at the top. Attention is drawn to the small flame at the top of the apparatus and the students are told to listen carefully. As the H_2 is consumed, air rushing in through the hole in the bottom makes the apparatus vibrate, and a clear 'whistle' can be heard.

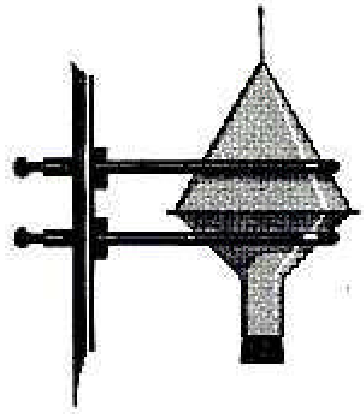

Figure 2

The frequency of the whistle changes with time, as the average molecular weight of the gas in the apparatus increases. With the lights dimmed, and the students paying careful attention to the change in the frequency of the low-intensity whistle the apparatus emits, the demonstration becomes 'striking' when the gas in the container reaches one of the explosive mixtures of H_2 and O_2 — and a loud detonation is heard as a flame shoots out of the bottom of the apparatus.

Demonstrations And The Theory Of Cognitive Change

Some might argue that demonstrations, by themselves, are sufficiently powerful as a teaching device that all we have to worry about is simply doing them. Sarason, however, suggested the following rule for curriculum development or curriculum reform: "A good idea, whose time has come, is no guarantee of success".[13] We'd like to propose a corollary to Sarason's rule: An ideal demonstration, done 'properly', is no guarantee that students will learn what we thought we demonstrated.

Instead of having the students play the role of passive observers of a demonstration, we might use the demonstration as the basis of a phenomenon that White and Gunstone describe as a POE task — from *Prediction*, *Observation*, and *Explanation*.[14] The first step in a POE task is to ask students to predict the outcome of some event, such as what might happen during a demonstration. They are then asked to describe what they observe, and finally asked to reconcile any conflict between what they predict and what they observe. Much has been written in recent years about the misconceptions students bring to chemistry[15] and the fact that these misconceptions are difficult to change.[16] Demonstrations, by themselves, won't overcome misconceptions, but they can provide the basis on which conceptual change is built.

Strike and Posner[17] have proposed a model of conceptual change that begins when students become *dissatisfied* with their present concept. They argue that dissatisfaction is necessary for conceptual change to occur, but not sufficient to induce the change. The student must *understand* the new concept they have been asked to learn. The new concept must also seem *plausible* to the students. And, the new concept must seem *fruitful* — it must seem worth learning. The demonstration of Avogadro's hypothesis in Figure 1 provides the basis for the first step in this model, the stage at which students begin to question the conceptual understanding they bring to the course.

Conclusion

If you accept the arguments in this paper, you can think about demonstrations in terms of the following guidelines.

- There is no evidence that students learn from demonstrations, by themselves.
- There is some evidence that students remember the visual images of a demonstration long after

they forget the words.

- Good demonstrations provide a basis on which learning can be built.
- Demonstrations don't have to be spectacular — or dangerous — to be useful.
- Demonstrations that contain an element of surprise, which don't behave the way students might expect, are often the most charming.
- Demonstrations that are the most charming are those that students remember.
- Demonstrations that are charming can therefore facilitate both the learning of chemistry and the retention of this knowledge.
- Demonstrations that students find ‘exocharmic’ might therefore be those that best teach chemistry.

You might also note that the spectacular (and often dangerous!) demonstrations that attract some students to chemistry might be driving others away by giving students an unrealistic image of what chemists do.

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