Communicating Science via Demonstrations

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Science is one of the most important forces affecting human society. The differences between the way we live now, at the dawn of the twenty-first century, and the way our ancestors lived, say, two hundred years ago, are due mostly to science and its resultant technologies. It is impossible to understand contemporary society without some appreciation for science, how it works, and what it tells us about the physical world. Science is fundamentally a human endeavor, driven by the same impulses that motivate much of human activity: curiosity about the unknown, the thrill of discovery, delight in creativity, and the benefits derived from understanding. Fundamental, too, is the desire to share the curiosity, thrill, delight, and benefits. This desire to share is perhaps most acutely displayed by science teachers, whose deepest desire is to effectively communicate the beauty of science, both in and out of the classroom. One of the most effective means of communicating this beauty, of stimulating curiosity, and of sharing the thrill of discovery in science is through demonstrations of physical phenomena. Through my experience in presenting demonstrations, I have come to appreciate that there are characteristics common to effective demonstrations, and I wish to share some of these with you in what follows.

CLARITY OF PURPOSE

To assure that a demonstration communicates effectively, a teacher must have a clear idea about the purpose(s) and value of presenting the demonstration. This means knowing *what* the demonstration is about, *why* it is to be used, *how* it should be presented, and *where* and *when* it will be presented. The purposes might include displaying phenomena, illustrating principles, conveying attitude, sparking interest, nurturing curiosity, making connections, and so on. Engaging people of all ages through the senses in carefully crafted and well-orchestrated scientific adventures is my penultimate purpose. My ultimate purpose is to trigger cerebral and emotional discourse within the individual and among individuals to heighten the joy of learning.

Before selecting a demonstration, I always ask myself, What is the point? My purposes for using demonstrations in the classroom and in other public settings generally include displaying science phenomena and illustrating scientific principles. However, even more importantly, demonstrations convey the presenter's attitude toward science as a human endeavor, and in turn, learners' attitudes can be influenced by teachers doing experiments in classroom settings. Chemistry demonstrations help focus students' attention on chemical behavior and properties, and they increase students' awareness and knowledge of chemistry. The direct observation of a phenomenon as provided in a demonstration can stimulate the observer to develop an immediate concept of the phenomenon. A demonstration can also transform an abstract concept from the theoretical and imagined to the observed and real. Sometimes demonstrations are presented solely for the entertainment value of fire, smoke, and noise. However, to approach demonstrations simply as a chance to show off dramatic chemical changes or to entertain students is to fail to appreciate the opportunities they provide to communicate scientific concepts and to acquire knowledge of the properties of chemicals.

The demonstration should be a process, not a single event. The instructional purposes of a presentation dictate whether a phenomenon is demonstrated or whether a concept is developed and built by a series of experiments. In demonstrations, the teacher's knowledge of the behavior and properties of the chemical systems is key to successful instruction, and the way in which the teacher safely manipulates the chemical system serves as a model not only of technique but also of attitude. Demonstrations can involve student participation through responses to questions and suggestions, such as What will happen if you add more of . . . ? Even in a demonstration where the teacher directs the flow of events, the teacher can ask the same sort of "what if" questions and can proceed with further manipulation of the chemical system. In principle and in practice, every demonstration is a situation in which teachers convey their attitudes about the experimental basis of chemistry, motivate their students to conduct further experimentation, and lead them to understand the interplay between theory and experiment.

Demonstrations should not, of course, be considered a substitute for laboratory experiments. In the laboratory, students can work directly and at their own pace with the chemicals and equipment and make their own observations and discoveries. In the classroom, students witness chemical changes and chemical systems as manipulated by the teacher. The teacher controls the pace and explains the purposes of each step. Both kinds of instruction are integral parts of the education we offer students.

A HIERARCHY OF TEACHING AND LEARNING CHEMISTRY

In teaching and in learning chemistry, teachers and students engage in a complex series of intellectual activities. These activities can be arranged in a hierarchy that indicates their increasing complexity [*1*]:

(1) observing phenomena and learning facts
(2) understanding models and theories
(3) developing reasoning skills
(4) examining chemical epistemology.

This hierarchy provides a framework for including demonstrations in the teaching of chemistry.

At the first level, we observe chemical phenomena and learn chemical facts. For example, we can observe that at room temperature sodium chloride is a white solid composed of cube-shaped crystals. It dissolves in water to form a solution with different characteristic properties of its own. One such property, electrical conductivity, can be readily observed when two wire electrodes connected to a light bulb and a source of current are dipped first into a sample of the sodium chloride crystals and then into the solution. Additional phenomena and facts can be introduced: the white solid has a very high melting point, the substance is insoluble in hexane, its chemical formula is NaCl, etc.

At the second level, we explain observations and facts in terms of models and theories. For example, we teach that NaCl is an ionic, solid compound and that its aqueous solution contains mobile, hydrated ions: sodium cations, $Na^+(aq)$; and chloride anions, $Cl^-(aq)$. The mobility accounts for the electrical conductivity of the solution. The solid, which consists of Na^+ and Cl^- particles, is said to have ionic bonds; that is, there are electrostatic forces between the oppositely charged particles. The ions are fixed in place and arranged throughout the solid in a regular three-dimensional array called a face-centered cube, an arrangement that explains the cubical shape of the crystals. Here, the teacher can introduce a discussion of the ionic-bond model, bond energy, and bond distances. Similarly, a description of water as a molecular, covalent substance can be presented. The ionic- and covalentbonding models can be compared and used to explain the observed properties demonstrated by a variety of compounds.

At the third level, we develop skills that involve both mathematical tools and logic. For example, we use equilibrium calculations in devising steps in a scheme for separating substances in aqueous solution. In these calculations, we combine the solubility-product, weak-acid dissociation, and complex-ion formation constants for competing equilibria in analyzing the behavior of a mixture of ions. The logical sequence of steps in the separation scheme is based on an understanding of the equilibrium aspects of solubility phenomena.

At the fourth level, we are concerned with chemical epistemology. We examine the basis of our chemical knowledge by asking questions such as, How do we know that the cation of sodium is monovalent rather than divalent? and How do we know that the crystal structure of sodium chloride can be determined from x-ray data? At this level we deal with the limits and validity of our fundamental chemical knowledge.

Across all four levels, the attitudes and motivations of both the teacher and the student are crucial. The attitude of the teacher is central to the success of interactions with students. Our motivation to teach is reflected in what we do and in what we do not do, both in and out of the classroom. Our modes of communicating with students affect their motivation to learn. All aspects of our behavior influence students' confidence and their trust in what we say. Our own attitudes toward chemicals and toward chemistry itself are reflected in such matters as how we handle chemicals, adhere to safety regulations, approach chemical problems, and explain and illustrate chemical principles. As I said at the outset, the most important purpose that lectures and demonstrations serve is to give teachers the opportunity to convey an attitude toward chemistry—to communicate to students an appreciation of chemistry and its usefulness, its cohesiveness, its value as the central science and as the science of the familiar, and its intellectual excitement and challenges.

PRESENTING EFFECTIVE DEMONSTRATIONS

In planning to use a demonstration, I always begin by analyzing the reasons for presenting it. Whether a demonstration is spectacular or quite ordinary, I undertake to use the chemical system to achieve specific teaching goals. I determine what I am going to say about the demonstration and at what stage I should say it. Prior to the lecture, I practice doing the demonstration. By doing the demonstration in advance, I often see aspects of the chemistry that help me formulate both statements and questions that I will use in class.

Because one of the purposes of demonstrations is to increase the students' ability to make observations, I try to avoid making statements like "Now I will demonstrate the insolubility of barium sulfate by mixing equal volumes of 0.1 M barium chloride and 0.1 M sodium sulfate solutions." Instead, I say, "Let us mix equal volumes of 0.1 M barium chloride and 0.1 M sodium sulfate solutions and observe what happens." Rather than announcing what should happen, I emphasize the importance of observing all changes. Often, I ask two or three students to state their observations to the entire class before I proceed with further manipulations. Occasionally pausing to point out an interesting observation or to pose a focusing question can increase student involvement by allowing them the opportunity to contribute to an explanation. In addition, I help students to sort out observations so that relevant ones can be used in formulating conclusions about the chemical system. Some valid observations may not be relevant to the main purpose of the demonstration. For example, when the above-mentioned solutions are mixed, students may observe that the volumes are additive. However, this observation is not germane to the main purpose of the demonstration, which is to show the insolubility of barium sulfate. However, this observation is relevant if the purposes include teaching about the additive properties of liquids.

Every demonstration that I present anywhere is aimed at enhancing the understanding of chemical behavior. The chemistry always speaks for itself more eloquently than anything

I can describe in words, write on a chalkboard, or show electronically on a screen. Modern technology now enables us to show an avalanche of text, a multitude of photos, and simulations of almost anything. The Internet provides access to mountains of information of widely varying validity. When technology or the Internet is used in an instructional program, the purpose for its use must be clear, and it should be the best way to achieve the purpose. Their convenience makes them attractive, but descriptions, photos, and simulations of phenomena are never as striking as the real thing.

In addition to following the advice given by Richard Ramette in his essay "Exocharmic Reactions" [*2*], here is a sampling of what to keep in mind when using demonstrations:

(1) Be clear about the purpose(s) for doing the demonstration. What is the point you wish to make?
(2) Plan and base your classroom lectures on one or several carefully selected demonstrations.
(3) Study the details of the procedures to be followed, and practice more than once what you will be doing. Remember that you are presenting yourself as a skilled professional who clearly understands the science involved in the demonstrations.
(4) Make sure to allow enough time for the demonstration. Be deliberate and do not appear rushed.
(5) Prepare an outline or, even better, a "mini-script" to help your pacing.
(6) Be confident in your presentation and always show enthusiasm.
(7) Keep the area of the demonstration clean and clear. Ask the audience to focus their attention on the area of your work.
(8) Be sure to stage your demonstration so everything is visible to your audience. Place an elevated platform above the table to improve visibility. Use a white table cover and white backgrounds for color changes. Use black backgrounds for white or cloudy phenomena and light emission. Scale the demonstration to fit the size of the audience, or if this is not feasible, use audio-visual devices as appropriate (see page xxxiii for information about such devices).
(9) Practice, practice, practice!
(10) Demonstrations never "fail." A result may be unexpected or unanticipated by you, but this should be welcomed as an opportunity and a teachable moment, especially because it allows you to demonstrate the skill of analyzing a phenomenon that may be as puzzling for you as for your audience. Be prepared to try to explain whatever happens, but if you are not sure, admit the limits of your understanding. Tell the class that you will try to resolve the problem and will share what you learn and try again during the next class meeting.

Good teachers entice others to make connections between new observations and what they already know. Good teachers also encourage observers to share their observations. In the process, teachers often gain deeper insight into and appreciation of the science and beauty of a demonstration. The requirements for an effective demonstration go beyond the mere mechanics of mixing chemicals and manipulating equipment. In addition to the skillful handling of materials, an engaging stage presence is also essential to successful demonstrations and thus is conducive to better learning. Teaching is, I believe, the ultimate performing art.

USING THIS BOOK

This volume contains a single chapter entitled "Color, Light, Vision, Perception." A substantial introduction addresses the science background for the demonstrations that follow. The demonstrations are grouped into sections that deal with the production of light, the properties of light, perception and vision, photoemission (fluorescence and phosphorescence), and photochemistry. Each demonstration includes its own discussion, which employs terminology and concepts that are placed in broader context in the introduction. Accordingly, when teachers read the discussion section of any particular demonstration, they may find it helpful to refer to the introduction for background information. For additional information teachers may wish to consult other sources, including the references provided with the demonstrations.

Each demonstration has seven sections: a brief summary, a materials list, a step-by-step account of the procedure to be used, an explanation of the hazards involved, information on how to store or dispose of the chemicals used, a discussion of the phenomena displayed and principles illustrated by the demonstration, and a list of references. The brief summary provides a possible rationale for using the demonstration as well as a succinct description of the demonstration. The materials list for each procedure specifies the equipment and chemicals needed. Where solutions are to be used, the directions sometimes call for preparing stock amounts larger than those required for the procedure. The teacher should decide how much of each solution to prepare for use in practicing the demonstration and for the actual presentation. The availability and cost of chemicals may also affect decisions about the volumes to be prepared.

The procedure section often contains more than one method for presenting a demonstration. The alternative procedures sometimes offer different methods for displaying the same phenomenon, and in some cases they may demonstrate additional properties of the system of interest.

The hazards and disposal sections include information compiled from sources believed to be reliable. We have enumerated many potentially adverse health effects and have called attention to the fact that many of the chemicals should be used only in well-ventilated areas. In all instances teachers should inquire about and follow local disposal practices and should act responsibly in handling potentially hazardous material.

The purpose of the discussion section is to provide the teacher with information for explaining each demonstration. We include the discussion of chemical equations, relevant data, and properties of the materials involved, as well as a theoretical framework for understanding the phenomena demonstrated. Again, we remind teachers that they should refer to the chapter introduction for additional background information. Finally, each demonstration contains a list of references used in developing the procedures and providing information for the demonstration.

A WORD ABOUT SAFETY

Jearl Walker, who was a professor of physics at Cleveland State University and editor of the Amateur Scientist section in *Scientific American*, has been quoted as saying, “The way to capture a student’s attention is with a demonstration where there is a possibility the teacher may die.” Walker is said to have caught the attention of his students by dipping his hand in molten lead, by gulping a mouthful of liquid nitrogen, or by lying between two beds of nails and having an assistant with a sledgehammer break a cinder block on top of him. Walker reportedly has been injured twice, once when he used a small brick instead of a cinder block in the bed-of-nails demonstration and once when he walked on hot coals and was severely burned.

I disagree strongly with this kind of approach. Chemical demonstrations that result in injury are likely to confirm beliefs that chemicals are dangerous and that their effects are bad. In fact, every chemical is potentially harmful if not handled properly. That is why every person who does science demonstrations should be thoroughly knowledgeable about the safe handling of all chemicals used in a demonstration and should be prepared to handle any emergency. A first-aid kit, a fire extinguisher, a safety shower, and a telephone must be accessible in the immediate vicinity of the demonstration area.

Demonstrations involving volatile material, fumes, noxious gases, or smoke should be rehearsed and presented only in well-ventilated areas. Local procedures and ordinances for the disposal and storage of chemicals and equipment must be strictly followed. Wearing eye protection is mandatory everywhere, and shielding an audience from potential hazards, such as flying sparks, noxious fumes, ear-piercing sounds, etc., should be part of careful planning. Several of the demonstrations in this book can be hazardous. The procedures are written for experienced chemists, who fully understand the properties of the chemicals and the nature of their behavior. The authors take no responsibility or liability for the use of any chemical or procedure specified in this book.

I urge care and caution in handling chemicals and equipment. Remember to have clarity of purpose for every demonstration by answering the question What is the point?

REFERENCES

1. I have adapted many ideas from Paul Saltman's address at the Third Biennial Conference on Chemical Education, which was sponsored by the American Chemical Society, Division of Chemical Education, and held at Pennsylvania State University, State College, Pennsylvania (1974); see *J. Chem. Educ*., 52, 25 (1975).
2. R. W. Ramette, "Exocharmic Reactions," in B. Z. Shakhashiri, *Chemical Demonstrations*, vol. 1, pp. xiii–xvi, University of Wisconsin Press: Madison (1983).