Paper

On the use of chemical demonstrations in lectures

Paul H Walton

Department of Chemistry, University of York, Heslington, York YO10 5DD. UK.
E-mail: phw2@york.ac.uk

Introduction

It is something that you hear often from students and colleagues: "*I remember clearly the time when I first saw a piece of sodium dropped into water...*" It must be almost the universal experience of chemists to have seen this demonstration, and to remember it with such clarity and, sometimes, affection. What is it about a simple experiment that it holds such a place in people's memories? Maybe it is the slight element of danger, or the illustration of theory in vivid, tangible form, or perhaps it is the sheer entertainment value of the noise, the flame and the action. Whatever the reason, chemical demonstrations—the reaction of sodium in water is a particular example—appear to have a significant effect on observers. People believe there is a positive effect on observers, and this view is supported by the enormous volume of 'tried and tested' demonstrations that are widely published (e.g. in *J. Chem. Ed.*) and are used by chemistry teachers at all levels.[1] In addition to those, a long and distinguished history of demonstrations exists with Faraday's lectures perhaps being the first real, lasting example of the impact of chemical demonstrations on audiences; the legacy of his Christmas lectures continues today. There are also many available resources; numerous books exist on the subject, and information on the World Wide Web seems to grow weekly. In short, there appears to be little doubt that demonstrations excite and 'charm' students[2] and have educational benefits (Figure 1).

Figure 1. 'Barking dog' demonstration—ignition of CS_2 and NO, performed in a well-ventilated laboratory.

Despite the large amount of available material on how to perform certain demonstrations, a careful search of the literature shows that there is not much agreement on the educational value of demonstrations; given the general acceptance of demonstrations as educationally beneficial, this is somewhat surprising. Reporting on the WPI conference 'Demonstrations as a Teaching Tool in Chemistry: Pro and Con' Beall relays the comments of Kelter who says that "*The primary purpose of demonstrations should be to entice students to ask questions and develop a classroom situation where questions are asked freely*".[3] Shakshiri in his introduction to '*Chemical Demonstrations: A Handbook for Teachers of Chemistry*' argues how carefully planned demonstrations can make a positive impact on a student's understanding.[1] Others criticise the use of demonstrations, making the point that they are time-consuming and often are merely present for entertainment rather than educational reasons.[3] There is currently no strongly persuasive evidence for or against the educational benefits.[4] Maybe the lack of a strong indication reflects the difficulty in assessing the educational value of demonstrations.

Student Survey

In an attempt to evaluate the benefits of lecture demonstrations, we have carried out our own empirical survey on a group of undergraduate students. The students were asked to complete a questionnaire after they had attended a lecture course (Acids and Bases, first year undergraduate) that was augmented with demonstrations; the results are given in Table 1. The results strongly support the notion that demonstrations are popular teaching tools. Importantly, the results show that a very large proportion of the students agreed that demonstrations helped them understand the theories—an encouraging link between demonstrations and educational value.

The results of this simple survey encourage the belief that the use of demonstrations is an important part of chemistry higher education, and that they have educational value. This paper offers practical advice and tips to those who are convinced by the positive evidence and are considering the use of demonstrations. By encouraging people to try out demonstrations in their teaching, it may generate further discussion about their educational value.

Table 1. Results of student survey on the use of demonstrations. Sample size was 87 first year honours chemistry students, surveyed directly after a lecture course which contained demonstrations

	Question	**% Either totally or partially agreeing**
1.	Demonstrations help me understand theories	87
2.	Demonstrations are a waste of time	0
3.	Demonstrations keep my interest during the lecture	95
4.	One demonstration per lecture is the correct frequency	98
5.	A live demonstration is better than a ‘video’ demonstration	60
6.	All demonstrations should be colourful or noisy	71
7.	The most effective demonstration is where there is an element of danger	79

Using Demonstrations

There seem to be three main hurdles confronting those contemplating demonstrations: worries about safety, lack of confidence on the part of the teacher, and the time and effort needed to put together a successful demonstration. All these are important considerations but not insurmountable, and methods for overcoming these hurdles are discussed below.

i) Time commitment

There is little doubt that setting up and performing a demonstration either in class or lecture is both time-consuming and needs considerable motivation on the part of the teacher (a point which is often not lost on students). There are two golden rules for preparation; the first is always to practise the demonstration in advance; the second is to make sure that the demonstration is relevant to the material being taught. Implementation of both of these golden rules requires time and effort in the research in finding an appropriate demonstration and the physical act of practising it.

In terms of finding out an appropriate demonstration, a vast number of resources are available. Perhaps the best sources are ‘*Chemical Demonstrations: A Handbook for Teachers of Chemistry*’ by Shakishiri,[1] ‘*Chemical Magic’* by Ford,[5] ‘*Tested Demonstrations in Chemistry’* by Alyea and Dutton[6] and ‘*Demonstrating Chemistry’* by Humphreys.[7] There are enough demonstrations described in these volumes to keep a teacher going for most of a career. Shakishiri’s texts are excellent: each demonstration is linked in detail with the background chemistry and the methods for performing the demonstration. Such is the comprehensive coverage of the volumes that they should be an essential part of a chemistry department’s library.

The World Wide Web

In terms of speed and coverage nothing can surpass the World Wide Web. Inserting ‘chemical demonstration’ into a search engine returns a veritable plethora of sites. The problem, of course, is the reliability of such sites; here some discretion and professional judgement are required. Nevertheless, one quickly acquires a list of good sites. A bonus of these sites is that they may contain video or still images of demonstrations that are useful in themselves, although it is not clear whether a live or recorded demonstration is best (see the results of the student survey above). A short list of useful web sites (with some commentary and a personal rating) is given in Table 2, although there are very many others.

Table 2 Selected Web sites with information about demonstrations

http://www.chem.leeds.ac.uk/delights/
A very comprehensive site maintained by Mike Hoyland at Leeds. There are lots of chemical details for about 40 lecture demonstrations—mostly the experiments that Mike Hoyland performs in his lecture to school children. Particularly valuable about this site are the video clips of the various demonstrations and the very thorough chemical details. Well worth a look.
Rating = *****

http://chemlearn.chem.indiana.edu/demos/democont.htm
A good number of selected demonstrations. Some chemical details are given. There are also some descriptions of the underlying chemistry.
Rating = ***

http://www.chem.uiuc.edu/demos/
About 10 demonstrations are described here, some of which are only tenuously related to chemistry. There are some very good still photographs, and also some video clips. Content is slightly below degree level.
Rating = ***

http://genchem.chem.wisc.edu/demonstrations/
Lots of demonstrations (>100) are described here. Nearly all have still photographs. What is good about this site is that the demonstrations are broken down into the various branches of chemistry, and it is easy to navigate your way around. For instance the 'inorganic chemistry' section has some very colourful transition metal demonstrations. There is also a beautiful silver mirror demonstration (the best I've seen) described here; unfortunately, precious few details are given. Less good about the site is that the demonstrations are hardly described in terms of preparation or chemistry.
Rating = ****

http://chemistry.csudh.edu/oliver/demos/index.htm
About 10 techniques are described. These are not so much lecture demonstrations, but more like laboratory procedures. Also, the content is probably below degree level. What is attractive about this site though, is the very thorough way in which each demonstration is described, with good use of stills and video clips.
Rating = ***

http://chem01.usca.sc.edu/proton/ppdemo.htm
There are about six fairly basic demonstrations described in excellent detail. There are no pictures or videos to help the viewer, but the demonstrations seem to be effective and simple to perform. Rating = **

http://journals.springer-ny.com/chedr/bang.html
A site dedicated to a single demonstration (the Pd-C catalysed explosion of H_2 and O_2). The site is excellent. The preparation, safety and chemistry details are very good. If you ever perform this particular demonstration, then look at this site first.
Rating = *****

http://www.shsu.edu/~chm_tgc/chemilumdir/chemiluminescence.html
The starting point if you want to perform a chemiluminescence demonstration. Lots of videos, photographs and procedures. There are also links to other chemiluminescence web-sites (of which there are very many). The only criticism is that it is difficult to unearth the chemical/preparation details if you are interested in performing any of the demonstrations.
Rating = ***

http://www.flinnsci.com/homepage/chem/chemdem.html
There are only about 10 demonstrations, but this is a very well laid-out site. Each demonstration is described in great detail, with each having some assessment of hazards. Most of the demonstrations are for effect rather than for teaching, but you may find something that ties in with your teaching subject matter.
Rating = ***

http://users.erols.com/merosen/demos.htm
An excellent site, with about 40 demonstrations. The demonstrations cover a range of chemistry. Each demonstration is described in very good detail—some have pictures and video-clips. The site author has also included ideas from others about tips/improvements. Probably one of the first web-sites to look at if you are thinking about doing a lecture demonstration.
Rating = *****

http://antoine.frostburg.edu/chem/senese/101/demos/resources.shtml
This site is a selected collection of other chemical demonstration web sites. Most of the material is 'kitchen chemistry' designed to be done at home. However, there are some very nice descriptions of 'old' demonstrations (e.g. elephant's toothpaste from the decomposition of hydrogen peroxide). If you want to entertain your audience, then this site may be a good starting point.
Rating = ***

On the other golden rule "*always practise the demonstration immediately before the class*", there is very little substitute for actually carrying out the demonstration oneself, no matter how many times it has been done beforehand. Only by practising it can one get a clear idea of the difficulty of the demonstration. It can also reveal the unexpected. Simple things like glassware size, temperature effects, etc. can ruin a demonstration in class if they are not right. By practising, one can also assess the impact and timing of the demonstration, which are both important aspects. It should be noted that a demonstration which takes longer than 5 minutes to perform is probably not appropriate as part of a lecture.

Naturally, all of this preparation and practice requires time and effort, and there is a calculation to be done to assess whether it is worth it. In balancing effort with value, my suggestion is to try using a demonstration and see how it changes the way that students perceive your teaching as shown, for example, by course evaluation questionnaires. I have never regretted spending time developing a demonstration for lectures; the student feedback has always been overwhelmingly positive (see above). It is perhaps worth pointing out here, that one demonstration per class or lecture is probably enough. Certainly, all student feedback that we have obtained has suggested that this frequency is about right. In other words, one does not have to develop very many demonstrations to benefit from their impact. One further point about the time involved in preparation and practice is that there are usually willing volunteers around in any department. It is surprising what knowledge (and motivation) is available from academic and non-academic colleagues; it is always worth asking someone. In some institutions this has been taken a step further with the formal identification of a member of staff (often a non-academic) whose role it is to help in the preparation of demonstrations. If such a person is available, then they are invaluable in that they will have experience of many demonstrations and will know immediately what to and what not to do. Departments may want to consider whether technicians or similar persons could be asked to become 'expert' in this area.

ii) Confidence

The next potential hurdle to performing demonstrations is a lack of confidence on the part of the teacher. This lack of confidence has two aspects. One is the personality of the teacher, where he/she may feel that chemical demonstrations do not fit in with the adopted teaching style. The second area is where the teacher is not confident that demonstrations add anything to the subject matter. In addressing both concerns, one should note the evidence that suggests that demonstrations could add to chemical education.[1, 3] Even with abstract subjects, such as group theory and atomic wave functions, where it is not immediately apparent what, if any, demonstration can be used, there is often something that can be shown or done. For example, in the teaching of atomic wave functions, a standing wave can be demonstrated with the use of a 'slinky spring'. Others have been able to demonstrate in lectures the emission spectra of hydrogen using a simple hand-held spectroscope, (although a willing student volunteer is required). Even if the demonstrations simply communicate the teacher's motivation and enthusiasm along with the principles, then they are surely worthwhile.

To enhance the value of demonstrations in class, the following method seems particularly good. The teacher performs the demonstration and asks students to write down their observations in a simple table (Figure 2). After the students have completed the observation side of the Table, they are asked to pass it to another student for him/her to complete the deductions side of the Table, against the other student's observations. This very simple exercise (of observation and deduction) is central in any practising chemist's thinking and—when coupled with theory—probably is the essence of what chemists do as part of their profession.

Figure 2. Observation/deduction table.

Observation	**Deduction**

iii) Safety

The final potential hurdle to performing a demonstration is that of safety. There is no doubt that this is a very important consideration when it comes to performing chemical demonstrations in front of an audience. Safety considerations must be paramount, and this stance necessarily restricts many of the more spectacular demonstrations. I believe that the message is simple: as teachers of chemistry we are obliged not only to teach accurately, but also to convey a professional and responsible attitude towards the handling and use of chemicals. Seen in this light, it is apparent that demonstrations in class can be used as part of communicating such a responsible and professional attitude. For instance, consider the very simple demonstration where a basic aqueous solution containing universal indicator is made acidic by mixing it with solid carbon dioxide. The demonstration, which is visual and dramatic, going through some attractive colour changes, helps to illustrate the point that not all acids (CO_2 in this case) are proton donors in the first instance. It is a relatively easy exercise to work through the potential hazards of the demonstration, and the appropriate procedures for preventing accident. Such information can be presented to students in class before performing the demonstration. The very act of going through the hazard assessment and then practising the safety measures (safety glasses, rubber gloves etc.) in front of the students is an important and beneficial message to communicate.

In practice, there are several reasons for demonstrations to be ruled out on safety grounds. These are as follows:

(a) Demonstrations that have the potential to give out noxious gases or fumes.
(b) Uncontrolled flames, explosions or detonations (NI_3 is a borderline case here).
(c) Very loud noises (e.g. ignition of CH_4/O_2 mixtures)
(d) Demonstrations that could give out solid or liquid projectiles (e.g. flying corks from 'pressure demonstrations'), for instance from the reaction of sodium bicarbonate and an acid in a sealed test tube).
(e) The department's insurance policy does not allow them (always worth checking!)

Whilst this may seem to be an unnecessarily constraining list that successfully removes most of the 'best' demonstrations, it does not mean that the more spectacular demonstrations cannot be shown. Firstly, there is usually video footage available that can be played in a lecture. Videos of the more spectacular demonstrations (e.g. ignition of cotton wool soaked in liquid oxygen) can be found on the Web. In saying this, there is a word of caution to add in the use of videos. A live demonstration is always more impressive (see Table 1); the difference between a live and recorded demonstration is similar to the difference between live performances and TV. Furthermore, in a live demonstration there is ample opportunity for the teacher to communicate his/her attitude towards handling the chemicals.

Secondly, portable fume hoods are now more widely available. These can easily be brought into a lecture theatre (if it does not already have a fixed fume cupboard) to allow one to perform demonstrations that would otherwise be ruled out. Also, modern fume cupboards are often transparent on all sides, allowing the audience to see through the 'back' of the fume cupboard to the demonstrator who faces the audience. For instance, the ignition of a mixture of magnesium and barium perchlorate powders would be normally ruled out because of the potential of an uncontrolled flame and the generation of clouds of dust. Performed within a portable fume cupboard, this spectacular demonstration presents very little hazard to the audience (both flame and fumes are contained) and none of the visual impact is lost (Figure 3).

Indeed, with a portable fume cupboard, many of the more spectacular demonstrations can be considered. The only extra item to check is whether the filter for the fume cupboard is both regularly maintained and appropriate for the demonstration that is to be performed.

In the absence of a portable fume cupboard, it is always possible to perform the demonstration outside the classroom, say in a laboratory. Of course, this means that the students have to be moved from a classroom to a laboratory. Obviously, this disruption to a class is unsatisfactory, but the hassle of doing it should never be used as an excuse for doing the demonstration in a class room where it is patently unsafe; in those cases do not do that demonstration.

Figure 3. Use of portable fume cupboard to demonstrate ignition of barium perchlorate and magnesium powders.

Conclusions

Evidence presented herein and elsewhere suggests that the use of chemical demonstrations in class add to the student learning experience. Notwithstanding the likely benefits of demonstrations, there are questions to ask and answer before ever performing a demonstration. The most important of these questions is that of safety. But, with appropriate safety controls and common sense, safety procedures can not only be followed in full, but can also be amplified by the use of a demonstration.

No doubt there are teachers of chemistry who will still find it difficult to include demonstrations in their classes, for whatever reasons. However, in every case I know of where teachers have started to use chemical lecture demonstrations, they have continued, motivated by the positive impact they have had on their students and on themselves.

References

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