

Using demonstrations to stimulate inquiry and students' thinking

L'ús de demostracions per estimular la investigació i el pensament dels estudiants

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abstract

This article describes how demonstrations can be used to stimulate inquiry and initiate the process of inquiry-based science education. This means doing demonstrations not just for fun or to illustrate some topic, but to catch students' attention, and engage them in the inquiry process by asking questions and suggesting solutions. Some examples of such an approach are given using a selection of science demonstrations, used in a lecture in Barcelona in November 2013. The article focuses on the engagement phase of the 5E enquiry model, which is being development in the TEMI project, a new FPY IBSE project.

keywords

Demonstrations, questioning, discrepant events, 5E model, IBSE.

resum

Aquest article descriu com es poden utilitzar els experiments demostratius per estimular la investigació i iniciar el procés d'ensenyament de les ciències basat en la indagació. Això significa fer experiments demostratius no només per diversió o per il·lustrar algun tema, sinó també per captar l'atenció dels estudiants, així com per involucrar-los en el procés d'investigació per mitjà de preguntes i el suggeriment de solucions. Alguns exemples d'aquest enfocament es donen mitjançant una selecció de demostracions científiques que es van presentar en una conferència a Barcelona el novembre de 2013. L'article se centra en la fase d'implicació del model d'indagació 5E, que és el model emprat en el projecte TEMI, un nou projecte d'ensenyament de les ciències basat en la indagació (ECBI).

paraules clau

Experiments demostratius, formulació de preguntes, controvèrsies científiques, model 5E, ECBI.

Introduction

Demonstrations are widely used in lectures and in lessons to capture student's interest or to illustrate something. Katz (2005) is well-known as a science demonstrator and said this about using demonstrations in teaching:

Magic is science without explanations. In presenting demonstrations, either explanations are often omitted or too much information is given. An

effective demonstration should promote good observation skills, stimulate thought, arouse curiosity, present aspects of complex concepts on a concrete level, and, most important, be the basis for class discussion. Explanations should contain enough information to satisfy the audience's curiosity as to what took place and why, and should serve as a starting point for further inquiry for those individuals who need more details.

Science demonstrations may be used in magic shows without explanation or in teaching with the explanation and connections to the topic being taught. Often the student is a passive recipient of impressions or ideas, rather than an active participant in such demonstrations. As part of the Tempus SALiS project on «Student Active Learning in Science», we developed a lecture demonstration to show how demonstrations can be used to encourage students to think and become more actively involved, thus promoting



Figure 1. Peter Childs giving his demonstration lecture in Barcelona.

scientific inquiry and learning (Childs and Hayes, 2012).

This article describes the approach used in the lecture in Barcelona in November 2013 (fig. 1) as a model for using the various examples in a teaching situation. The format of the lecture was that a demonstration was introduced and performed and then the audiences were asked questions to help them think about what they had seen, to suggest explanations, propose hypotheses to explain what had happened and suggest further experiments to test their ideas.

In a teaching situation, it is envisaged that each example would be developed and would lead to further discussion and experimentation, consolidating the material and developing a deeper understanding of a scientific approach to problems. The initial demonstration would be the first stage, engagement, of the inquiry process as used in the 5E model of inquiry (fig. 2), and is used to kick-start the lesson and to engage students in the learning process (Bybee et al., 2006).

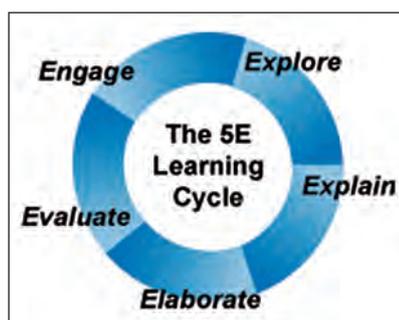


Figure 2. The 5E model of inquiry (<http://www.bsos.org/bsos-5e-instructional-model>).

This was not possible in a lecture and this article follows the format of the lecture: first, the demonstration is described, with information on how to do it; sample questions are then given to stimulate students' thinking about the example, and finally an explanation is given for the teacher. However, it should be stressed that the teacher is not expected to jump straight to giving the answer but should lead the students through the process of questioning, hypothesising and testing ideas, only giving the explanation at the end of the process. The approach taken is very similar to the new EU FP7 project «Teaching Enquiry with

Mysteries Incorporated» (TEMI) (<http://teachingmysteries.eu/en>).

The purpose of this inquiry-based teaching approach is to:

- Engage the students' interest and stimulate their curiosity as a prelude to inquiry.
- Stimulate thinking and to get your students involved with their «minds-on».
- Use demonstrations and experiments to encourage thinking, not just to provide answers.
- Not to use demonstrations just as science magic, because we want to end up with answers, not just amazement.

The importance of questioning

I keep six honest serving men
(They taught me all I knew);
Their names are What and Why and
When And How and Where and Who.
RUDYARD KIPLING (1865-1936)

This famous poem by Rudyard Kipling reminds us of how important questions are in teaching. We want to get our students involved in thinking, discussing, and proposing solutions and questions are the way the teacher can start this process. Westaway (1929, p. 28) emphasised the importance of questions in doing demonstrations in school:

But in a school the lecture-room is a place for teaching, and the demonstration table is the teacher's laboratory bench. The teacher works experiments, often because the experiments are beyond the pupil's skill; the lesson consists of questions and answers all the time —directed questions, and in case of emergency leading questions, and answers which are used for cross-examination and further questions.

Some points to bear in mind when using demonstrations for inquiry-based learning:

- Make it interactive: the demonstrator should interact with the audience and get them involved.

- Ask questions throughout to raise the level of involvement.

- Get them to make observations as the demonstration proceeds.

- Stimulate thinking by showing unusual things, often known as *discrepant events* (Liem, 1990; O'Brien, 2010), which can be used to provoke discussion.

- Encourage discussion amongst students, so they argue with each other about what is going on and sharpen their own ideas.

- Ask students to suggest why the demonstration works and what it means.

- Get them to suggest possible reasons to explain the phenomena and how they could test them experimentally.

- Ask «what if?» to take the demonstration further by extending it, and if possible do this by proposing hypotheses and testing out their ideas experimentally.

We want to get over the idea that hypotheses are not speculations but can be tested by further experiment, and that experimental evidence is used to test them.

Good teaching is more a giving of right questions than a giving of right answers.

JOSEF ALBERS (1888-1976)

Choosing suitable demonstrations or experiments

When deciding what demonstrations to use to engage students either in a lecture or classroom context, we need to consider a number of factors.

We need to consider:

- The background, ability and level of students.

- The topic being taught.
- Identify suitable demonstrations or experiments that are:

- a) Safe.

- b) Low-cost.

- c) Right level.

- d) Arouse curiosity.

- e) Stimulate questions.

- f) Lead to fruitful inquiry.

There are a wide range of demonstrations and activities in every area of science that could be used. The difference lies in how we present them and use to stimulate inquiry, curiosity and critical thinking. The demonstration is not an end in itself, or the end of the story, but is deliberately chosen as the starting point for an adventure in inquiry for your students, which will cause them to engage with the science and develop their understanding through minds-on and hands-on activities. One source of suitable ideas is classed under the heading of *discrepant events* (Liem, 1990; O'Brien, 2010).

A discrepant scientific event is a surprising occurrence—such as corn growing faster in the dark than in the light—that challenges learners' preconceptions. Because they at first appear to be non-academic in nature and frequently differ from what is expected, these tidbits can stir the interest of even the chronically disinterested student. The moment a student proclaims: «No, that just isn't possible; it can't work that way», a window of opportunity opens for the student to gain a better understanding of his or her world (Wright, 2014).

In the following section, some of the demonstrations covered in the lecture, and some additional ones, are described to illustrate the approach used.

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Sample demonstrations to initiate inquiry

Colour changes

Colour changes are one way of recognising a chemical change, and when the changes are unexpected or are presented in a «magic show» format, they can be used to stimulate thinking. Some examples are given below.

1) Magic writing

How to do it:

This is then sprayed with a colourless solution and a pink message appears. When left for some time, this message disappears. It will reappear when sprayed again.

What is happening? Some questions to ask:

Why can a colourless solution produce a pink colour? (The students might recognise the colour of phenolphthalein from titrations and guess that the solution sprayed might be an alkali.)

How might you test the solution that was sprayed? (Litmus or universal indicator would show that the solution was basic. Testing with phenolphthalein would produce the same colour as that observed.)

Why does the colour slowly fade? Is this due to light or something in the air? (This is more difficult to explain and there could be several explanations. If it was due to light, then we could leave the message in the

dark and see if it still disappeared. However, knowing the colour is due to an acid-base indicator that goes from colourless to pink with base might lead to the suggestion that if it changes back, an acid must be involved to neutralise the base or that the base evaporates reversing the reaction.)

Where could the acid come from? Does it come from the cloth or paper or from the air? (The same thing happens for cloth and paper so it is more likely to be the air.)

Is there anything acidic in the air? What about carbon dioxide? How could you test this hypothesis? (We could put the coloured cloth in air with no carbon dioxide. We could test whether bubbling carbon dioxide through dilute sodium hydroxide plus phenolphthalein, changes the colour from pink to colourless. We could put the paper or cloth in a jar containing carbon dioxide.)

Explanation and set-up:

An invisible message is written using phenolphthalein indicator solution on a sheet of paper or the back of a lab coat. When sprayed with dilute sodium hydroxide (e.g. 0.1M NaOH or another dilute alkali), the acid-base indicator changed from colourless to pink. However, air contains a small amount of carbon dioxide (an acidic gas), which slowly reacts with the alkali, neutralises it, and thus removes the pink colour. This is a slow reaction due to the low concentration of carbon dioxide in air and the fact that it has to diffuse into the paper or cloth and react. The pink colour will reappear if sprayed again with dilute alkali.

2) Water to wine and back again

How to do it:

Three glasses or beakers (A, B, C) are lined up each one-third full

of colourless liquid. When A is poured into the central one B, it turns pink. When C is poured into the central one, the pink colour disappears.

What is happening? Some questions to ask:

What does the colour change from colourless to pink remind you of? (The students will be familiar with acid-base indicators, and the only one showing this colour change is phenolphthalein.) Which beaker must contain the phenolphthalein? (Must be the central one, B.)

What must be present in A to cause the pink colour to appear? (An alkali causes phenolphthalein to turn pink.) What sort of substance causes the pink colour of phenolphthalein due to an alkali to disappear? (An acid produces the colourless form of phenolphthalein, so C must contain an acid.) If we add an equal volume of C to B as the volume of A (the base), what can we say about the acid? (For the colour to disappear fully, the acid must be more concentrated than the alkali, so that it neutralises it and produces an acidic solution.)

Explanation and set-up:

It is important to have equal volumes in each glass/beaker to start. When added together, they should not overflow from the middle glass/beaker. The central beaker B contains water with a few drops of phenolphthalein and should be colourless to start with. Beaker A contains 0.1M sodium hydroxide solution. When A is poured into B, the pH increases and the phenolphthalein indicator changes into its pink form. Beaker C must contain an acid which is more concentrated than the alkali in A, so that it will neutralise it. 0.2M hydrochloric acid or 0.1M sulfuric acid could be used. Part of the acid will neutralise the alkali

An invisible message is written using phenolphthalein indicator solution on a sheet of paper or the back of a lab coat. When sprayed with dilute sodium hydroxide (e.g. 0.1M NaOH or another dilute alkali), the acid-base indicator changed from colourless to pink

and the excess will convert phenolphthalein to its colourless form.

How could you turn it pink again? You would need to add more alkali, enough to neutralise the acid.

This simple demonstration could be used to introduce the more complex «Water into wine» series below. It is about acid-base reactions but also introduces the importance of concentrations.

3) Anyone for wine? Water into wine

How to do it:

A cup of «water» is poured into a glass and turns pink. Water into wine! This is then poured into a series of glasses and first turns colourless (lemonade); then it fizzes (7-Up lemonade); turns white and cloudy (milk), and finally the milk turns pink (indigestion mixture).

What is happening? Some questions to ask:

How can the various changes be explained? (The demonstration presupposes some knowledge of acid-base chemistry and indicators, and tests for common ions. These are often done in introductory chemistry classes, and thus this demonstration is an interesting way to revise this material.)

What could change water into wine and then back again?

The yellow solution is an iron(III) salt, which will be acidic. On adding a base, a yellow/red precipitate of iron(III) hydroxide is formed. Iron is a transition metal and forms coloured complexes and compounds

(The characteristic colour of phenolphthalein should suggest that the initial «water» is a dilute alkali and the first cup contains phenolphthalein.) To remove the colour we need an acid, so the second glass contains a small amount of a more concentrated acid than the original alkali.

What causes the fizzing to produce «lemonade»? What fizzes with an acid? (It could be a carbonate or hydrogencarbonate, as there is no smell.)

What causes the colour change to «milk» in the next glass? What could the white precipitate be? It must be something that reacts with the chemicals from the previous step. [White precipitates commonly covered in introductory chemistry classes include barium sulphate (test for sulphate ion) or silver nitrate (test for chloride ion). This would mean that the acid used in step 2 was either sulfuric acid or hydrochloric acid.] How could you check which it was?

In the final step, the white precipitate turns pink. What could cause this? (Since we know we have phenolphthalein present, the final glass must contain an alkali, enough to neutralise any remaining acid, thus restoring the basic colour of phenolphthalein. The white precipitate appears to turn pink.)

The idea is to try to get the students to work out the chemistry of the demonstration, and

then to try and replicate it themselves to check whether they were correct.

The explanation and set-up:

The original glass contains 1-2 cm³ 0.1M NaOH(aq) diluted with water and the second glass, a few drops of phenolphthalein, which turns pink in the alkali. The third glass contains a few drops of 1M sulfuric acid. This is concentrated enough to neutralise the alkali and change the phenolphthalein back to colourless. The fourth glass contains a small amount of solid sodium hydrogencarbonate or a few drops of sodium hydrogencarbonate concentrated solution. It fizzes as the solution is poured in, as the acid reacts with the hydrogencarbonate and liberates carbon dioxide. The fifth glass contains a few drops of barium nitrate or barium chloride solution. This forms a white precipitate of barium sulphate from the sulphate ions in the solution. The sixth glass turns pink, colouring the white precipitate. It contains a few drops of 1M sodium hydroxide, which neutralises any remaining acid and turns the solution alkaline and the phenolphthalein pink. The glasses appear empty to start with, as small volumes of liquid are used, which are hidden in the bottom of the glass.

There are many variations on this demonstration and it provides a good way to revise acid-base reactions and tests for common ions. You could extend it by asking students to devise their own series of colour changes using the chemistry they have covered in class.

4) Red blood or blue?

How to do it:

A spray bottle contains a yellowish solution. When sprayed on to a blank piece of paper, writing in a mixture of red and blue letters appear. Alternatively,

when poured into two «empty» glasses or beakers, one turns blood red and the other, dark blue.

What is happening? Some questions to ask:

How can one solution produce two totally different colours? (There must be something different on the paper or in the glasses to produce two different colours.) What sort of reaction could it be? (They could be acid-base reactions with two different indicators.) The yellow colour of the initial solution is a clue: what could this be due to? What tests could you do on this solution to check its identity? Acid or base? What happens if you add a base? (The intensity of the colours is another clue as they are much more intense than normal indicator colours.)

The explanation and set-up:

The yellow solution is an iron(III) salt, which will be acidic. On adding a base, a yellow/red precipitate of iron(III) hydroxide is formed. Iron is a transition metal and forms strongly coloured complexes and compounds. The first glass contains a small amount of thiocyanate ions (from potassium thiocyanate, KCNS, or ammonium thiocyanate, NH₄CNS), which form an intense blood-red complex with iron(III) ions. The second glass contains a small amount of potassium ferrocyanide (K₄[Fe(CN)₆]), which forms a dark-blue precipitate (Prussian blue) with iron(III) ions. The invisible writing is made by painting the letters on paper or cloth using thiocyanate ions (red letters) or ferrocyanide (blue letters). This is a very colourful demonstration, which challenges students to think how one solution can produce two different colours.

Other colour changes are possible using iron(III) ions by

forming different complexes or changing the pH, so that one solution can be changed into several different colours. Get your students to investigate some of the reactions of iron(III) ions, and then set up their own series of colour changes. This can be done in the same way as the «water to wine» demonstration above, using a series of «empty» glasses.

Density

Often density is taught in a very traditional way that emphasises the content —definition, equation, units, etc.—, and at the end students often do not understand the concept of *density* (which is a composite quantity of mass and volume). We need to start with concrete experiences and phenomena, which cause students to think and ask questions, and which eventually leads them to the concept of *density*.

1) Two sorts of soft drink

How to do it:

Set up a large glass or plastic tank and fill nearly to the top with water. Put two cans of soft drink —a regular and diet version in the water (fig. 3). Get your students to observe what happens and suggest an explanation.

What is the difference between the two cans? (The regular drink sinks further down in the water than the diet drink, which floats higher up. There may only be a small difference in behaviour but one will be lower in the water than the other)

What has happened? Some questions to ask:

What is the difference between the two cans? (The regular drink sinks further down in the water than the diet drink, which floats higher up. There may only be a small difference in behaviour but one will be lower in the water than the other.) What is causing the difference? It is worth asking students the question: what is the same between the two cans and what is different? (They have the same shape and volume; they are made of the same material: aluminium. They have different labels, and if you read the labels, the students will find they have different compositions: the regular drink contains sugar and the diet drink, an artificial

sweetener.) Why would this make a difference to their behaviour in water? (A closer look at the label may reveal the mass of sugar and the suggestion that the cans don't have the same mass. The students should then weight the two cans, after drying them.) What is observed? (The regular drink is heavier than the diet drink. So now we have a real physical difference: the volumes are the same, but the mass is different.) Why do some things sink in water and some things float? What property of an object makes it float?

The explanation:

When the two cans are weighed, the regular drink is heavier than the diet drink. The volumes are the same, so the difference in mass (~ 11 g) means that they float differently. Does this work with other brands of drink? Would you expect it to work with 500 cm³ plastic bottles of the same brands? Students should make a prediction and then test them experimentally on different soft drinks and containers. The question is why do some things sink in water (stones, iron, concrete, rubber bungs) and other things float (wood, plastic, cork). Students should now investigate what floats and sinks and come up with ideas as to why materials have different properties. What is the property that makes one object sink and another float? It is something to do with size and volume: if the volumes are equal, heavier objects tend to sink. What is the relationship between the volume of an object and hence the volume and mass of water displaced, and the mass of the object? Students can find out experimentally (and not be told!) that things sink when their mass exceeds the mass of water displaced, and objects float when their mass is less than the mass of water displaced.



Figure 3. The experimental set-up.



Figure 4. The blue bottle.

Now get them to explain why a piece of iron (or concrete) sinks but a steel (or concrete) boat floats.

The blue bottle

How to do it:

A stoppered bottle has been prepared beforehand and is colourless (fig. 4). When shaken it slowly turns blue. The more it is shaken, the stronger the colour. When allowed to stand, the colour slowly disappears. The stronger the colour produced, the longer it takes for the colour to disappear. The bottle will continue to work many times over several hours. It can be prepared before a lesson or done on the spot.

What has happened? Some questions to ask:

Is this a chemical or a physical change? What might explain the observations? There is some sort of reversible reaction with a colour change. Is it due to putting in energy? If we used a magnetic stirrer bar to mix the liquid only, would it change colour? (There is a colour change which happens on shaking and when the air and liquid are mixed. The colour change and loss of colour are slow processes, suggesting slow reactions.) What might be causing the colour change? It

happens when the air and liquid are mixed. What is in the air that might be reactive? (Students often suggest it is due to CO_2 in the air, so that it is an example of acid-base chemistry. However, there is very little CO_2 in air and it would soon be used up.) How could you check this idea? (Flush out the air with CO_2 and then see if it still works.) Nitrogen is unreactive, but air contains 20 % of oxygen gas, which is both reactive and an oxidising agent. Is the colour change due to oxygen in air reacting with a chemical in the solution? How could we test this idea?

(We could flush out the air with a chemically inert gas, CO_2 or N_2 , and see what happens or flush it with pure oxygen and see what effect it has.) How do we know it is something in the air? (Fill the flask to the top with water. Allow the blue colour produced to disappear. Why does it turn blue when we add water? Then shake and see if the blue colour is produced when there is no air present.) Why does the solution turn blue if we add more water carefully? Would it happen if the water was boiled first?

The explanation:

The 500 cm^3 conical flask or bottle is set up beforehand by dissolving 5-10 g NaOH solid in ~ 200 cm^3 water, and then adding an equal mass (5-10 g) of glucose. When both solids are dissolved, add a drop or two of methylene blue solution (in ethanol). The liquid will turn blue and eventually turn colourless. Do not add too much methylene blue or the colour will be too strong and take too long to disappear. The solution gradually turns yellowish after some time, but will still work. It can be used many times over several hours. If indigo carmine is used, a red colour is produced to give a red bottle.

All the evidence suggests that the colour change is due to mixing the air with the liquid. A chemical reaction occurs to produce a blue colour. On standing, a second reaction destroys the blue colour. Both reactions are quite slow. Adding water (which contains dissolved air) also produces a blue colour. Boiled water produces no colour change. The solution in the flask is an alkaline solution of glucose. Glucose is a reducing agent, and in alkaline solution can be oxidised by oxygen gas. Methylene blue is a redox indicator: it is blue in the presence of oxygen (oxidising) and colourless in a reducing solution. When the colourless solution is shaken, some of the air and oxygen dissolves in the water; the dissolved oxygen reacts with methylene blue turning it blue. When shaking is stopped, the glucose reacts slowly with the oxygen, and when the oxygen is used up, the solution goes colourless again. The reversible reaction can be done many times until either the oxygen is used up or the glucose is used up. It will get slower as the concentrations decrease (Campbell, 1963; Vandaveer and Mosher, 1997).

Is this a chemical or a physical change? What might explain the observations? There is some sort of reversible reaction with a colour change. Is it due to putting in energy? If we used a magnetic stirrer bar to mix the liquid only, would it change colour? (There is a colour change which happens on shaking and when the air and liquid are mixed)



Figure 5. The experimental set-up.

The disappearing water

How to do it:

Add water to a polystyrene cup and it appears to disappear (fig. 5). When turned upside down, the water does not run out. Where has it gone?

This can also be done as a version of the three card trick: water is poured into one of three identical polystyrene cups; they are then shuffled and the students asked to say which cup contains the water; they choose the right one, and when it is turned upside down, nothing comes out! They may try again, but still the water has disappeared.

What has happened? Some questions to ask:

Where has the water gone? What could cause it to «disappear»? Can the water really have vanished? How could you check that the water was still present? (Have a balance available to show that the mass of the cup still includes the water.)

The explanation:

When the students can look inside, they see a whitish solid instead of the water. One of the cups contained a small amount of sodium polyacrylate powder (as used in babies' disposable nappies/diapers). When the water is added, it is slowly absorbed to form a solid gel. When the cup is turned upside down, the gel traps the water so that it doesn't flow out. It is important to allow time for the water to be absorbed

and to use the right amounts of solid and water.

The water can't have disappeared. If the cup was weighed before and after, it is clear the water is still there. The water must have been turned into a form where it cannot run out or perhaps the cup has a secret bottom? If you do this again with a glass beaker, then the students can see what is happening. When sodium polyacrylate is used in nappies/diapers, the liquid doesn't disappear: it is trapped in the gel in a solid form.

Polar and non-polar liquids

How to do it:

Set up two burettes, one with water and one with a colourless non-polar liquid (e.g. hexane).

Charge a plastic pen or comb with static electricity (by rubbing on dry hair or a jumper). Adjust the taps to get a steady stream of liquid running into a beaker (fig. 6). Observe what happens to the two streams of liquid. Do they behave in the same way? In one case, the jet of liquid is deflected: is it repelled or attracted to the comb? In the other case, the stream of liquid is unaffected. If the students carefully smell the two liquids, one smells organic and the other doesn't. (It can be revealed that one is water and the other, an alkane or oil.)



Figure 6. The experimental set-up.

What has happened? Some questions to ask:

What effect does it have on the two streams of liquid? Why is

What is the difference between these two liquids that explains the behaviour? Is the difference between organic liquids and other liquids? What other organic liquids could be tested? (The students could suggest an alcohol like ethanol or acetone.) Do these behave like water or like the hexane?

there a difference? (The comb or pen will also pick up small pieces of paper.) What has happened to the pen or comb? (It has picked up a static charge.) Why is one liquid affected and the other not? Why is the water stream deflected but the other stream is not? Is it because water is not an organic substance? (If ethanol or acetone is used in one burette, then there is a similar but smaller deflection to that observed with water.) So it's not just organic liquids. What's the difference between water and ethanol, and hexane that would cause the difference in behaviour? Does the same effect happen if a magnet is used?

The explanation:

What is the difference between these two liquids that explains the behaviour? Is the difference between organic liquids and other liquids? What other organic liquids could be tested? (The students could suggest an alcohol like ethanol or acetone.) Do these behave like water or like the hexane?

This is an example of electrostatics and solvent polarity.

The electrically charged pen or comb attracts the molecules in the polar liquid (water), but not the non-polar liquid (hexane). If

ethanol or acetone are tried, the stream of liquid is also deflected (but not as much as water), because these are both polar liquids. The liquids are polar because they contain polar molecules (with positive and negative ends), which are attracted to the charge on the comb. A magnet does not cause a deflection, because the liquids are not magnetic.

This is a good way to introduce the topic of polarity in molecules. Why are acetone and ethanol polar but hexane is not?

The burning steel wool

How to do it:

First take two lumps of steel (iron) wool, open one up so the wires are separated and squash the other piece into a tight ball. Show that if you use a Bunsen flame or a gas lighter, one of them will glow and catch fire and continue burning by itself, and the other will glow but then go out (fig. 7).

What is happening? Can a metal burn like wood? Is this a chemical or physical change? How could you tell?

The same demonstration is done again, but this time the terminals of a 9V battery are touched to the two samples of steel wool: one open and loose and the other tightly packed. The same behaviour is observed. The loosely packed steel wool glows and catches fire and continues to burn; the tightly packed one does not continue to glow after the battery is removed.

What has happened? Some questions to ask:

Why does the iron wire glow and spark in air? (The iron wire glows and sparks as it burns in air and the iron is oxidised with the evolution of heat. It continues to burn when the heat or battery is removed because the heat of reaction is enough to keep it

Why does the wire change colour in the process? (The steel wire changes colour as it is oxidised and increases in mass as it goes from Fe to Fe₂O₃. The same reaction happens whether it is initiated with a flame or a battery)

going.) Is it a chemical or a physical process? (The steel wool changes colour, there is a heat change and the mass increases.) If it is a chemical change, would you expect the mass to increase, decrease or stay the same? (Many students think that if things burn, they lose weight. When a metal oxidise, it combines with oxygen and increases in mass. This should be confirmed experimentally: the same reaction can be done on a top-pan balance using a white tile to protect the balance. As the wire burns, its mass is seen to increase. The students should be asked to explain this.)

Why does the wire change colour in the process? (The steel wire changes colour as it is oxidised and increases in mass as it goes from Fe to Fe₂O₃. The same reaction happens whether it is initiated with a flame or a battery.) Why does the wire behave differently if it is loosely packed or in a tight ball? How can a battery set iron wire on fire?

The explanation:

Why does a battery set the iron on fire? Iron wire is a good conductor of electricity, and when it shorts the battery terminals, a large current flows, which heats up the wire, and the heat produced is enough to raise the temperature so that the iron starts burning and reacting with the oxygen in the air. The same reaction happens if the wire is

heated in a Bunsen flame. The loose wire continues to burn, unlike the compacted wire, because the surface area is increased and the air can penetrate to keep the reaction going. The heat generated by the reaction is enough to keep the reaction going, but it needs the heat from the flame or from the electrical heating to start the reaction.



Figure 7. The burning steel wool.

Conclusion

I hope that this short article has shown how demonstrations can be used to stimulate questioning and initiate the inquiry process. You can probably think of other ways of using the same demonstrations described here and other questions to be asked. The important idea is for you, the teacher, to get into the habit of asking questions to get your students thinking. Catching the students' attention with an unexpected or discrepant event is the first stage of inquiry: engagement. In a classroom or laboratory, the demonstration is not an end in itself but the starting point for inquiry and student involvement. There are many more ideas available in books and on-line for suitable science demonstrations which can be used to stimulate students' thinking and inquiry.

The approach described here was used in the Tempus SALiS project (Childs and Hayes, 2012; <http://www.salislab.org>) and is also being used in the new EU TEMI project, and I am one of the University of Limerick's TEMI project team (Broggy et al., 2014). TEMI is a new FP7 project in IBSE, «Teaching Enquiry with Mysteries Incorporated» (TEMI), which is due to run from 2013 to 2016 (http://cordis.europa.eu/projects/rcn/108650_en.html). The aim of TEMI is to encourage teachers to use inquiry in science teaching by using a scientific mystery or discrepant event to engage students. This is then used to initiate enquiry in the classroom using the 5E model. Several cohorts of teachers in each partner's country will be trained to use mysteries or discrepant events to initiate inquiry in their own schools. One of the outcomes of the project will be a bank of tested activities for the engagement phase of science inquiry lessons.

I hope that this short article has given you some ideas for introducing demonstrations into your own classroom as a prelude to inquiry. If you can catch your student's attention and spark their curiosity, then half the battle is won. By asking questions, you can challenge them to observe carefully and think about what they see, and come up with their own explanations and suggestions for further work to test their ideas. The lesson can then proceed to investigate the topic and eventually come up with proper scientific explanations, for things that may have seemed at the beginning to be just magic. Using demonstrations in the way I suggest above starts by putting the «magic» back into science, so that the students become engaged and take on the personal

I hope that this short article has shown how demonstrations can be used to stimulate questioning and initiate the inquiry process. You can probably think of other ways of using the same demonstrations described here and other questions to be asked. The important idea is for you, the teacher, to get into the habit of asking questions to get your students thinking

challenge of explaining the magic in scientific terms.

Many demonstrations are available on-line (e.g. on YouTube), and these can be used instead of live demonstrations to initiate inquiry. The lecture covered more topics and can be seen on-line.

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