The Work of Science

Critical teaching ideas - Science Continuum F to 10
Level: Working towards level 8

Student everyday experiences

Students' experience of science at school can lead to a narrow, restricted and non-authentic view of science and the way it is done. Developing notions of who does science, where it is done and what it means to work in scientific ways is an important focus to explore with students.

Many students believe that science is all about dramatic discovery, rather than generating knowledge and creating explanations through repetitive work and the painstaking collection of evidence.

When conducting science investigations students rarely think about the 'thinking behind the doing' and the need for evidence that will be believable and acceptable to others.

Students do not distinguish between data and evidence. Students often believe a single datum is all the evidence required to support a conclusion. Many school science experiences support this idea. For example conducting one experiment on Boyle's Law is often presented as proving Boyle's Law.

Students often view practical work in school science as the means for verifying a fact or supporting a theory already presented in class. Students frequently view school science as belonging only to the classroom, and science content as not directly usable in everyday situations. Adding to this perception of lack of relevance is the persistent image that students have of scientists as male, balding, wearing glasses and a white laboratory coat with scientific instruments in their pockets, and looking manic.

Research: Skamp (2004), Gott, Duggan, Roberts & Hussain (1995), Berry, Mulhall, Gunstone & Loughran (1999), Tasker (1991), Chin, Mumby, Hutchinson, Taylor & Clark (2004), Aikenhead (2006)

Scientific view

Science is a human and creative activity. Scientists share some fundamental assumptions about evidence, data, and logic but they differ in their talents, imagination, intuition and courage. Given the same problem, two (groups of) scientists may explore it in different ways. Given the same results, two (groups of) scientists may create different explanations.

Scientists' work is focused on trying to improve their understandings of and explanations about the natural world. They construct their explanations based on evidence, by using data, imagination and logic, and the feedback on emerging explanations that comes from peer and public review.

Scientific investigations involve:

- being engaged with a scientifically orientated question
- giving priority to evidence in responding to the question
- using evidence to develop an explanation
- connecting the explanation to scientific knowledge
- communicating and justifying the explanation.

The concept of 'evidence' is complex and multi-faceted. Evidence and data are not equivalent terms. Data is directly recorded, often through observation. Not all data is equally valuable. For example, 'outliers' are data that are regarded as less valuable (and less valid). Data that has occurred only once, generated from investigations that might be flawed or not able to be reproduced, are regarded as less reliable. Data (and sets of data from multiple sources) that are considered reliable and valid are regarded as evidence. When the evidence supports outcomes that are, for example, impractical or expensive to implement, a higher level is demanded of the quality (validity and reliability) of that evidence.

Research: Bybee (2006)

Critical teaching ideas

- The purposes of scientific investigations are to generate knowledge and create explanations.
- Science investigations are conducted in multiple contexts and by a range of people.
- Scientific investigations are conducted in multiple ways that rely on the collection of a range of types of evidence. The ways an investigation can be validly conducted depend on the specific problem being investigated.
- The concept of what is evidence needs to be developed and should consider its credibility, acceptance, bias, status, appropriateness and reasonableness.
- Verification and reproducibility of investigations is another important process of science – one experiment is not enough.

Explore the relationships between ideas about the work of science in the Concept Development Maps – Scientific World View, Scientific Investigations, The Scientific Community, Science and Society.

Students need to realise that science is done by humans and that this has implications for the knowledge that is produced. They should also appreciate that there are assumptions made when doing any scientific investigations and that these assumptions have implications for the results.

Common practices in science include modelling, hypothesizing, predicting, analysing, sampling and using a control experiment. While these are important practices, not all are used in every context. The work of science integrates these practices with existing scientific knowledge and questions (things that are not known) to develop scientific knowledge further.

What does it mean to investigate scientifically? Doing science for both students and research scientists includes reflecting on what data is being collected, and how the collection is occurring. For example, students do not understand the concept of breathing just because they breathe. To develop the ideas of investigating scientifically, students need to discuss why scientific investigations are designed in certain ways. For example, students should be encouraged to recognise that:

- descriptive science investigations are designed to describe what is observed
- correlational scientific investigations seek to find connections between what is observed
- experimental scientific investigations seek to prove or disprove relationships.

Observation is one important source of data in the gathering of evidence which can be used in the creation of explanations.

The role of observation is further discussed in the focus idea Doing science authentically.

Research:Flick & Lederman (2006)

Developing ideas about what is evidence is also an important part of the process of creating explanations. Students need to be supported to develop the following understandings of evidence:

- Evidence should be considered in the light of personal and social experience and the status of the investigators. For example, the academic or professional status, experience and authority of the investigators will influence the weight placed upon the evidence.
- Evidence should be judged as to its credibility. For example, is the evidence consistent with conventional ideas, with common sense and with personal experience? The credibility of evidence improves with the level of scientific consensus supporting the evidence and sometimes depends on the type of evidence e.g. statistical versus anecdotal evidence.
- Evidence needs to be scrutinized for bias. Possible biases may come from having limited sources of information, intellectual rigidity or alliance with a particular idea such as religious fundamentalism, capitalism, scientism etc.
- Evidence can be given greater or less status, or even dismissed, because of its political significance or influential bodies/people. The user of evidence needs to have trust in the evidence.
- Evidence can be denied or dismissed for different reasons that may be appear illogical such as public or personal fear. Prejudice and preconceptions may play a part here.
- Evidence gathered within one set of rules may be quite different when viewed from a different set of rules. For example, engineers work within a different set of rules than do scientists, or builders, or pharmacists or wine makers.
- Evidence is drawn from the available data and so conclusions should be limited to these data. It is important not to go ‘beyond the data’, to make inappropriate generalisations, judgements or inferences. For example, if there is only a small sample it would be inappropriate to then conclude that this applies to everyone or everything.

Research: Gott, Duggan & Roberts (2003)

Teaching activities

Challenge some existing ideas.
There are many examples of science being conducted within your local community. For example a hairdresser uses science to:

- create solutions
- use different reaction types to colour, style and condition hair
- make predictions about the extent to which reactions have proceeded as they colour hair or apply heat to particular styling solutions.

Hairdressers also model their work before they try a procedure on a client and use their intuition based on experience of what will work on particular hair types.

Students should consider the scientists in their local community. Students can be challenged to find someone in their community who does science. They should interview them for 15-20 minutes about 'How they use evidence in their work as a scientist'. Students should prepare a report and communicate it to the rest of the class. In preparing their interview and report, students can be supported to develop a vocabulary of terms such as modelling, hypothesizing, predictability, analysing, sampling, intuition etc.

Practice using and building the perceived usefulness of scientific models.
While many scientific models are readily accepted today, this was not always the case. Using models and building their usefulness is an important part of understanding why some models are accepted and others are not. For example, students can trace the story of Milliken's famous oil-drop experiment with particular focus on his recording of data. The point here is that Milliken made comments in his data log book about some data that were 'beautiful' and some that were 'outliers'. Millikan won the Nobel Prize for Physics for this work. However there was also some controversy (the Milliken-Ehrenhaft controversy) over the reproducibility of his data and this is why there was a delay in the awarding of his Nobel Prize.

Further information about Milliken's oil drop experiment can be found at:

- Wikipedia: Oil Drop Experiment

Research: Niaz (2000)

Help students work out some of the 'scientific' explanations for themselves.
When conducting experiments in class it is common practice to pool class data. What effect does this have on the data itself and on the conclusions drawn from these pooled data? Pooling 20 pieces of data in a class is rather more like 20x20 pieces of data when the effect of the experimenter is accounted for.

To explore this effect have students do a survey/poll about a topic that they have studied. For example: Do parents of Year 7 students have different opinions on (an aspect of the topic such as 'is sand a solid or a liquid') compared to Year 8 parents?

Collect the data from each student and then analyse it as a class together. Are there differences because of gender, age of parents or year level of students? Also encourage students to see if they can identify trends in the pooled data. Students can consider questions such as:

- What differences are there?
- Are all the data valid and how would you decide this?
- How are you going to report these data – will you use statistical tools such as mean, median and mode?
- How are the statistical tools helpful and which would be the most appropriate choice?
- Do you have sufficient data or do you need to collect more evidence?
- What, if any, is the social context of the evidence and does this make a difference?

All of these different considerations become important when thinking about the quality of the pooled data. Students can be further challenged to consider the implications of their responses to questions such as:

- Did all students ask exactly the same questions, in the same way, at the same time? Does this matter?
- Does the pooled data look very different from an individual student's data?

Encouraging students to identify phenomena not explained by the currently presented scientific model.

The notion of a control experiment is often a confusing one for students. A control experiment is about reducing 'noise' ('noise' is the term used by scientists to refer to observations and other data that are irrelevant to the question being investigated) – this means that in the investigation everything except what is being tested is kept the same.

An example of this is the process for testing new drugs: an experimental group is given the new drug and a control group is given a placebo (fake). All other factors (such as age range and sometimes gender, lifestyle etc) are kept the same. This process tests what was intended and helps to create a new explanation or thinking around the use of the drug. The next step would involve the drug being tested in a normal, everyday environment (one where there is a range of ages, lifestyles, etc; that is, an environment where there is quite normal 'noise').

One common perception students have about control experiments is generated from the way they do experiments in class. For example, many science classes learn about Boyle's Law (the relationship between the pressure and the volume of a gas) in a relatively controlled way via an experiment in the science laboratory. In this type of experiment attempts are made to reduce 'noise' – since the experiment is aiming to establish the relationship between pressure and volume of a sample of gas, then, for example, the temperature of the gas is not changed.

However, leaving the experiment at this point means that very few classes explore this Law in relation to everyday examples and so the scientific model (Boyle's Law) is not used to explain everyday phenomena. This makes the development of understanding of the underlying concepts more difficult. Further exploring/experimentation needs to take place in different contexts so students can extend their understanding of Boyle's Law to help them understand how, for example, the pressure in car tyres would behave on a hot or cold day.

Students should be encouraged to further consider if there is a difference between how scientists would explore this issue compared with engineers. For example, scientists tend to deal with ideal environments while engineers explore ideas in specific situations. Do these two groups of people know their science differently?

In a similar way, students could think about how farmers might decide if the quality of their water is adequate for drinking by both their family and their stock as opposed to how scientists ensure the quality of water for people living in the city. Does this represent knowing and using science in different ways?