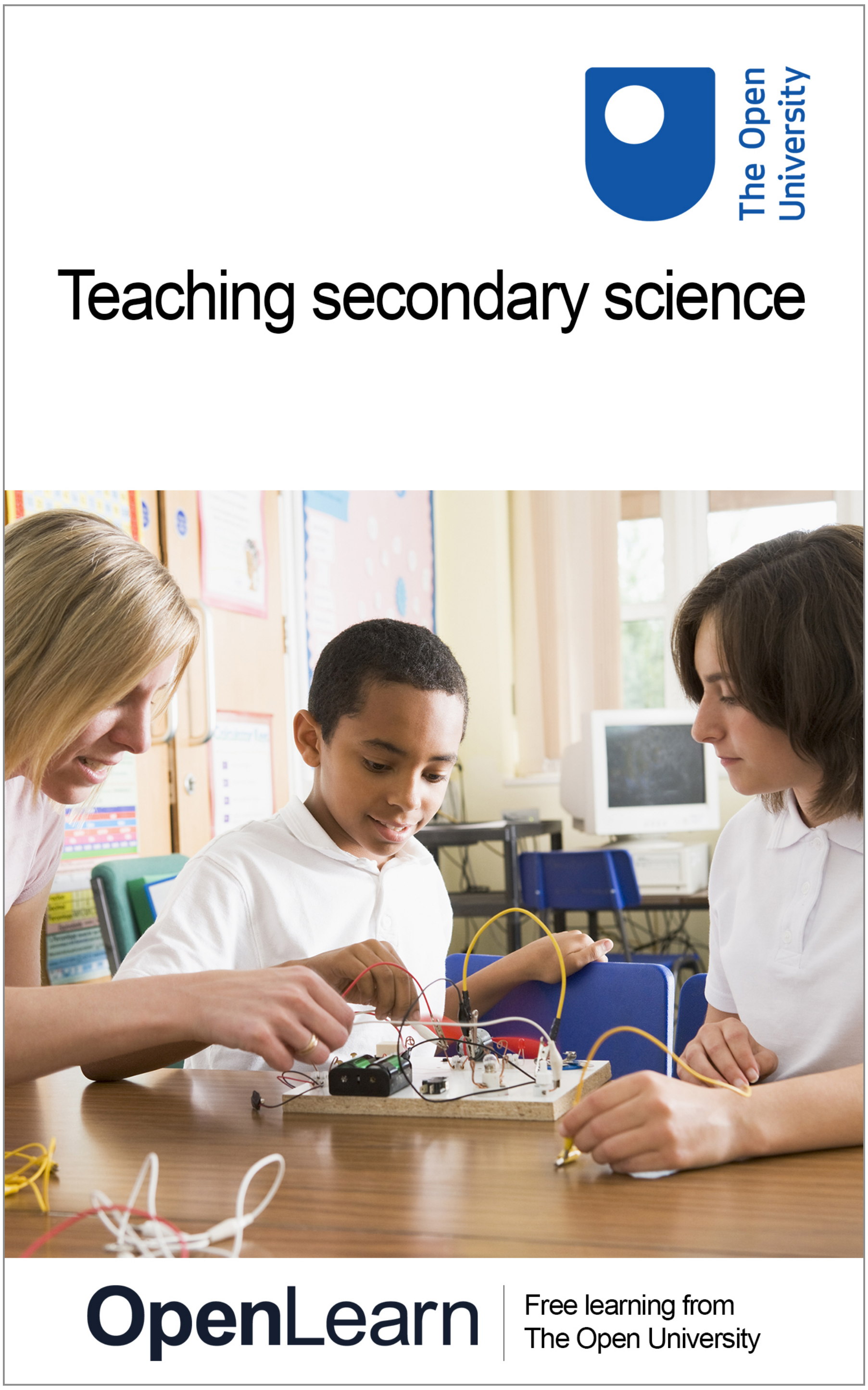
Teaching secondary science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Contents

Introduction

This free course, *Teaching secondary science*, is aimed at new teachers who are in training or embarking on their teaching career and working in school. It sets out to explore some of the key issues around teaching science in secondary schools. Engaging with these issues and debates will help you to reflect upon and develop your practice as a science teacher. You will also develop a greater awareness of the wider context of science education and how this affects science in the secondary school curriculum.

Section 1 examines how science is portrayed in and out of school before considering how such views impact on the teaching and learning of science. This sets the scene for the following sections. The second considers the purposes of school practical work and how it can be used more effectively to support students' learning. This is developed in Section 3, which examines how students can be engaged in the nature of science through practical work and other experiences. The final section focuses on why dealing with controversial issues in science education is important and the approaches that teachers can take.

This course examines science education from a learner-centred approach to teaching, which is underpinned by a constructivist view of learning – that learners construct knowledge and understanding for themselves through activities, experiences, thought and discussion.

Now listen to an introduction to this course by its author, Sandra Amos:

Audio content is not available in this format.

As you work through the activities you will be encouraged to record your thoughts on an idea, an issue or a reading, and how it relates to your practice. Hopefully you will have opportunities to discuss your ideas with colleagues. We therefore suggest that you use a notebook – either physical or electronic – to record your thoughts in a way in which they can easily be retrieved and revisited. If you prefer, however, you can record your ideas in response boxes within the course – in order to do this, and to retrieve your responses, you will need to enrol on the course.

This OpenLearn course is part of a collection of Open University short courses for teachers and student teachers.

Learning Outcomes

After studying this course, you should be able to:

- classify and analyse practical work according to its purpose and learning outcomes
- identify ways in which the nature of science can be reflected through school science
- use different resources and approaches to support students' understanding of the nature of science
- set out the case for the inclusion of controversial issues in the school curriculum
- select an appropriate approach to teaching controversial issues.

1 What do young people learn about science?

If you asked a random selection of people to brainstorm 'science', what do you think would be said? Although most students' formal science learning begins in school, they learn a great deal informally outside of school. Consider for one moment the out-of-school encounters you have had with science this week – science is all around us. Through this, students learn about the nature of science; how science is done, who does science, what science is valued and whether science is for them.

1.1 Views of science

As a science teacher, you are probably enthusiastic about science – but what are the views of others?

Activity 1 Views of science

Allow about 20 minutes

Ask people of different ages (including those of school age) what they think about science. You could do this through your social media networks. Ask them about their views of science now, as well as when they were learning it at school. What has led to their views?

What are the most common attitudes and feelings people have about science? What has led to these views and attitudes?

Not all views about science are positive. How science is portrayed in schools, the media and elsewhere contributes to how people view it. Images of science convey important 'hidden' messages about who does science and what science involves. In the past, textbooks in particular have been criticised for the messages they convey to young people.

Activity 2 Images of science

Allow about 20 minutes

Look at the pictures and photographs presented in science textbooks, news items and websites aimed at young people. What images of science and scientists are portrayed?

Past research has revealed the stereotype view of the scientist as a white male Einstein lookalike (Reiss, 2002). Different images of scientists are present in the media today, but has this changed the images that children and young people have of science and scientists?

Activity 3 Images of science

Allow about 20 minutes

Ask two or three children or teenagers who you know to draw a picture of a scientist or describe a scientist. Are the old stereotypes still evident in their drawing(s) and descriptions, or is the image changing? If so, in what ways are they changing?

You may have found that some people view science as 'difficult' or 'boring', and only for the 'clever' students. Science may not appeal to creative and artistic people who find it hard to relate to the impersonal image associated with science. They may have been put off by lacklustre teaching that failed to help them see the relevance of science to their lives and interests. Many people do not feel that they were successful in science at school; some are even hostile towards science or show pride in their ignorance of science. Images and views of science have implications for science teachers wanting to enthuse students. The challenge for science teachers is how to make science appealing and relevant to pupils with different interests and views.

1.2 Scientific knowledge

You may have found that people perceive science as a 'hard' subject or one that requires the student to memorise a lot of information. Science has indeed led to a body of knowledge about the natural world, but what is particular about scientific knowledge as opposed to, for example, historical knowledge or folklore?

The nature of scientific knowledge is closely tied to the nature of science itself. Whilst the scientific method seeks to eliminate biases and subjective ideas from its body of knowledge, to view scientific knowledge as 'fact' or 'truth' would be to ignore the nature of the human beings at the heart of it. In practice, knowledge is constructed through human senses – a process that will always involve an element of subjectivity. So scientific theories are not infallible, and there will always be competing views that require a judgement as to their validity.

Reflection point

What messages about scientific knowledge do you think should be communicated to pupils through school science and why?

Hodson (1998, p. 35) asserted that scientific knowledge is not a collection of facts, definitions and rules, but rather it is a:

> network of inter-rated concepts and propositions that stand or fall on their ability to describe, explain, and predict a range of observable phenomena, without being dependent on any single observation.

Hodson argued that students need to be aware of the distinction between theories that are used to explain phenomena and instrumentalist models (imaginary conceptual devices) that are used to predict, calculate and manipulate events. To what extent do you this is a feature of school science?

1.3 Science in the curriculum

One of the most important factors impacting on a student's perceptions of, and attitudes towards, science in school will be the department's schemes of work, and the type of knowledge and pedagogy promoted. Schemes of work will inevitably reflect examination specifications, any statutory curricula requirements that happen to be in force, any current political agendas and initiatives, as well as the values and beliefs about the subject held by the teachers developing them.

When people speak of 'knowledge', what do they mean by the term? Is there a shared understanding of the concept? From a philosophical perspective, knowledge is typically divided into three categories:

1. Personal knowledge can be thought of as 'knowledge by acquaintance' – the kind of knowledge someone claims to have when they say things like 'I know about dogs' or 'I know Mrs Smith'.
2. Procedural knowledge can be thought of as knowledge of how to do something – the practical skills of being able to ride a bike, kick a football or mend a leaking pipe, for instance.
3. Propositional (declarative) knowledge is sometimes caricatured as being the memorisation of facts. However, a higher order of propositional knowledge is 'conceptual knowledge'. This is demonstrated through an understanding of the interrelationship between 'facts' within a larger framework, such as scientific theories.

These three categories are shown in Figure 1.

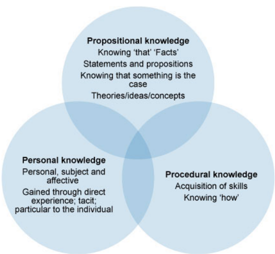

Figure 1 Knowledge relationships

The sort of science knowledge that is valued by the education system can be seen in the curriculum and by what is tested through examinations.

Activity 4 Science knowledge in school

Allow about 20 minutes

Look at the schemes of work and examinations papers from the different examination boards used by your school. Analyse the documents to identify the sort of knowledge that is being assessed and therefore valued. What is the balance of personal, procedural and propositional knowledge in each? What value is placed on conceptual knowledge as opposed to 'facts'?

1.4 The nature of science

The way that a teacher teaches science is profoundly affected by their views of the subject. For example, in teaching about particle theory, a teacher might put forward this concept as a fact and use it to explain how it can account for the properties of solids, liquids and gases. Another teacher might emphasise that the particle theory is a model of what matter is like, drawing attention to the way in which this idea developed and how it relates to evidence. Reiss (2002, p. 43) gives the popular view of science as consisting of:

> a body of knowledge about the world. The facts that comprise this knowledge are derived from accurate observations and careful experiments that can be checked by repeating them. As time goes on, scientific knowledge steadily progresses.

Reflection point

What views of the nature science do you hold? Do you agree with the popular view given by Reiss? Is science context- and culture-free? Or is scientific knowledge dependent on its cultural and social location? Are you an inductivist or a deductivist? A relativist or a positivist?

Defining the nature of science is contentious. Reiss (2002, p. 49) argued that science is 'not universal or a-cultural, but a collection of ethno-sciences set in a cultural milieu'. How do you think the work of scientists is affected by wider values, culture and social/political influences?

Activity 5 The 'Barry Marshall' story

Allow about 20 minutes

Barry Marshall, an Australian physician, was awarded the Nobel Prize for Medicine in 2005 for his work with Robin Warren on the role played by a bacterium in the formation of peptic ulcers. In this interview he recounts the story of this ground-breaking discovery.

View at: youtube:hDP8jQnOcSg

How does this account illustrate the view Reiss has of science? How does this support or contradict your views of science?

There is no consensus about the nature of science, and there are debates within and between communities of scientists, philosophers and science educators. We would expect a science education to teach pupils something about science concepts, but we should also expect it to teach them something about what science is, what scientists do, and the status of scientific knowledge. Without this, we exclude learners from the debate and impoverish their understanding of science.

2 What do students learn through practical work?

A key approach used to teach science in school is practical work. Science without practical work is hard to imagine, but familiarity can lead to it being used without thought being given to the learning outcomes it will support or whether it is the best type of activity to use.

2.1 What is practical work?

The term ‘practical work’ itself is vague and covers a broad range of activity.

Reflection point

What does practical work bring to your mind? What, in your experience, is the purpose of practical work? What is its role in helping pupils to acquire knowledge of science and the concepts that we want pupils to grasp? To what extent does practical work in schools reflect the nature of science?

Practical work is more than lab coats and Bunsen burners! It can serve several different purposes. It may aim to support the learning of science content, develop skills (e.g. using instruments, process or investigation skills), give students a feel for a phenomenon, develop their conceptual understanding or help students learn about the nature of science.

2.2 Students’ views of practical work

Teachers need to be alert to what students actually gain from practical work, as it may not be what was intended. In addition, the assumption that all students like practical work has to be challenged. Less confident students may be dominated by others and gain little from the experience. Therefore, practical work need to be scrutinised from the perspective of the student, and needs to be carefully planned and managed.

Activity 6 Investigating students’ perspectives

Allow about 30 minutes

Find out what students of different ages think of practical science work. To what extent do they enjoy it, learn from it and feel that it’s worthwhile? What do they learn about science and science content? You could find out what students think through a simple questionnaire or by talking to students.

2.3 Practical work and science content knowledge

Learning science content knowledge through practical work typically involves students completing tasks that have an outcome known by the teacher, such as measuring the loss of heat from cans insulated with different materials. When students do not obtain the expected results, they are often told that something must have gone wrong, or their results are explained away. What do they learn about science and themselves as a scientist from such experiences? Perhaps they learn that science is about getting the 'right' answers, or that they are not good at science.

However, such routine teacher-led practical work has the potential to support learning. Previous approaches include the 'discovery' method. In *Chemistry*: *Handbook for Teachers* for the original Nuffield Chemistry O-level course (The Nuffield Foundation, 1967, p.63), the following advice appears after a description of some of the practical work that pupils might undertake:

> given sound preparation and skilful guidance the class will discover or invent the main postulates of Dalton's atomic theory.

There does not seem to be any recognition here that this theory is an enormous leap of the imagination, not simply a generalisation of observations from practical work. Not only would it be unrealistically optimistic to expect pupils to construct these kinds of scientific theories for themselves, but it would also be a serious misrepresentation of the nature of science.

The teacher-constructed type of practical so often used also does not reflect the nature of science. But does this matter? Millar (2002) argued that practical work designed to support learning of content knowledge is about communicating what is already known and does not have to be an authentic science experience. Such experiences provide students with the opportunity to talk, write and think about phenomena 'from within the "mental landscape" and using the terminology of an imagined model' (Millar, 2002, p. 55). Through this it has the potential to build a bridge between objects and observable properties, and the realm of idea (Millar, 2002, p. 58).

The typical teacher-led practical work activities have an important role in school science education. However, done without thought and focus, practical work may not develop students' conceptual understanding; used unthinkingly, it may only entertain pupils and simply waste learning time. It is therefore imperative that science teachers understand the different types of practical work available and match tasks to specific learning outcomes. The Association of Science Education's (ASE) *Getting Practical* programme of professional development for teachers of science at the primary/elementary and secondary phases of education aims to improve the effectiveness of learning through practical science lessons. The website provides useful links and resources to support effective practical work in science.

Activity 7 Getting practical

Allow about 90 minutes

Spend some time exploring the *Getting Practical* website.

Read the *Getting Practical framework* (SCORE, 2011), which provides an outline for thinking about practical work in science, including what it can be used for, the different purposes of practical work and a checklist for best practice.

Use the framework to analyse and evaluate the practical work you have used in two or three lessons taught or observed recently. In particular, you should identify:

- the nature and purpose of the practical work
- how it supported students' achievement of the learning objectives.

Use the 'best practice' checklist to evaluate the use of the practical work and identify how it could be used more effectively.

3 How can students learn about the nature of science?

The nature of science is not something that can be taught in isolation from science content and process knowledge. Rather it is conveyed through how teachers approach the teaching of science, and in particular practical work in science. There are also activities that can help students understand the nature of science and how scientists work, which can enrich the science curriculum and make science more appealing to students.

3.1 Practical work and the nature of science

If the traditional practical work so commonly seen in science classrooms is used to support students' understanding of science content knowledge, how do they learn about the nature of science itself? What would be your response? Students to conduct their own investigations, perhaps? Certainly students can benefit in a number of ways from investigating their own questions. Even teacher-led investigations can support students' understanding of elements of the scientific process, but investigations seldom give them the full picture. Consider for a moment some of the key features of science that come readily to mind:

- asking questions
- hypothesising
- seeking evidence
- collecting and processing data
- critical evaluation
- developing theory.

This list in itself does not reflect the other dimensions to the nature of science, or the experience of real scientists such as Barry Marshall. These other dimensions include developing a cultural understanding of science, examining the applications and implications of science, argumentation, and the collaborative nature of science. Traditional practical work often fails to provide an understanding of these dimensions, although it may provide critical incidents that can be used as opportunities to convey important messages.

3.2 Using critical incidents

Common incidents in the science classroom can provide good opportunities for engaging students with the nature of science. Critical incidents as defined by Nott & Wellington (2002) and Wellington & Ireson (2012) include those that arise during practical work and confront teachers with decisions about a course of action. They focus on some examples of the incidents that experienced teachers will be familiar with, including:

- students not drawing what you expect when looking at cells under a microscope
- Canadian pondweed not producing sufficient oxygen for testing

- lamps in series circuits not being of the same brightness
- burning magnesium ribbon giving different results, with some finding a loss in weight and others a gain or no difference.

These examples confront teachers with how to handle unexpected results. Another common critical incident occurs when students deny the evidence they collect when it clashes with their current conceptual understanding. For example, if students investigating the factors affecting the time period of a swinging pendulum believe it is the mass of the weight that determines the time period, they may disregard the evidence that disproves this and simply believe they did the experiment wrongly.

Reflection point

How would you respond to the incidents given above? How might a teacher more focused on supporting students' understanding of the nature of science respond to these incidents?

Common approaches to the unexpected results include 'doctoring' or 'rigging' the practical (for example, adding oxygen to the test tube with the pondweed), explaining away the results ('The bulbs aren't identical!'), or blaming inaccurate measuring. These types of responses suggest that the teacher is focused on ensuring that the students get the 'right' results and, therefore, the 'right' science knowledge. Yet these incidents provide an opportunity to engage students in a dialogue about the nature of science and practical work. There is no right way to deal with the incidents described above, but here are some suggestions:

- **Cells under a microscope:** Ask the students to compare what they see to photographs of cells, after checking that they have not focused on bubbles.
- **Canadian pondweed:** Discuss why so little gas was produced and how to increase it.
- **Lamps in series circuits:** Try different bulbs to see whether an issue with the bulb is affecting the results.
- **Burning magnesium ribbon:** Discuss why results might be so varied and what scientists would do.
- **Pendulum period results:** Discuss why the students don't believe the evidence and how they could verify it.

By sharing and comparing results, practical work can reflect the collaborative nature of science. Repeating the work of others reflects the 'reproducibility' aspect of science and critiquing the work of others, the peer-review process.

3.3 Ideas and evidence

As well as making the most of critical incidents, more targeted activity is needed to support students' learning of the nature of science. An important aspect of this is 'ideas and evidence'. Through the ages human beings have come up with ideas to explain their experience of the world. Moving beyond superstition involves collecting and interrogating evidence to support or refute ideas, making 'ideas and evidence' central to the scientific endeavour.

Osborne (2002) argued that historical case studies can help a student to focus on what it means to do science. Incorporating the stories behind scientific discoveries can bring the nature of 'ideas and evidence' to life for students. It can also show that the ideas they may hold were once helped by famous scientists in the past. Such accounts can also convey other important messages about the nature of science and what being a scientist involves.

Activity 8 Scientific stories

Allow about 20 minutes

Now watch a video on the work of Van Helmont. (Alternatively, you can read a transcript.) How might this story be used in teaching the topic of photosynthesis? What messages does it convey about science, past and present?

An important and overlooked part of being a scientist is not always having the 'right' answer or 'truth'. Van Helmont's ideas about how plants get their food is one held by many people. Scientists have ideas, formulate hypotheses and collect evidence. Often the evidence refutes their hypotheses, but the value of that is not communicated to students who feel deflated when this happens to them. A culture of 'getting the right answer' is unhelpful and contrary to the nature of science.

There is support for teachers wanting to develop their science teaching practice. The Nuffield Foundation's 'Practical Work for Learning' comprises a set of resources that exemplify three different approaches to practical work: argumentation, model-based inquiry and science in the workplace. The Science Enhancement Programme (SEP), set up in 1998 by the Gatsby Charitable Foundation, developed innovative resources to enhance science education and support science teachers. The extensive set of publications and resources have now been transferred to the National STEM Centre eLibrary. This collection includes resources and activities to support the teaching of 'ideas and evidence'.

Activity 9 Exploring different approaches

Allow about 90 minutes

You should now explore:

- the SEP's 'How science works' resources, which are designed to support teaching and learning about the nature of science
- the materials under 'Teaching ideas and evidence in science at Key Stage 3'
- the Nuffield Foundation's 'Practical Work for Learning' project.

Use one or more of the activities in your teaching and then reflect on the outcomes. To what extent did the activity you chose support discussion and challenge the students' thinking? What learning outcomes were evident?

4 How can school science deal with controversial issues?

Science and controversy go hand in hand, and there are many examples of controversial issues in science both past and present. The question is how can this important aspect of science be dealt with in school?

4.1 Controversial issues in science

People who believe that students should be inducted into the nature of science argue that the science curriculum should present a more balanced allocation between scientific content (which covers established and uncontested scientific knowledge) and controversial and/or critical issues. For example, Boyle's Law and Newton's Law are established laws that preclude the students from making the connection between their learning and their world, unlike more controversial issues such as climate change or genetic engineering.

Arguably, including critical contemporary science topics in the school curriculum would help the 'conscientisation' of science students, enabling learning to occur through dialogue between the teacher and the student. Contemporary scientific knowledge is therefore constructed as the result of solving problems that relate to the student's world.

Reflection point

To what extent do you agree with or believe in the inclusion of critical or controversial topics in the science curriculum? How would you justify your position? Does the current science curriculum support 'critical pedagogy' or not? What are the challenges for the implementation of a critical pedagogy in science, and in your science specialism in particular?

Science is packed with issues that cause controversy, or have a moral/ethical dimension. Even topics that many scientists might regard as non-controversial, such as evolution, have been in the news in recent years when teaching a particular scientific theory clashes with religious beliefs.

Controversial issues involve value judgements – they cannot be settled or dealt with by evidence or 'facts' alone. A controversial issue also has to be considered important by a lot of people who hold differing views. (If only one person holds a particular view but everyone else holds an alternative view, then it is not controversial!) If you audit the science curriculum, you will see that there are many controversial and ethical issues.

4.2 Learning through controversial issues

The Wellcome Trust, the independent medical research charity, sponsored research into the value assigned to the teaching of socio-scientific issues in secondary and post-16 education. The resulting report by Levinson and Turner (2001) asserted that 'the ability to engage in discussion about the impact of science on society is increasingly seen as an essential part of people's education' (Levinson and Turner, 2001, p. 2). The current science curriculum supports this aspect of science education, placing greater importance on the nature of science and its relationship with society. Despite this, many teachers taking part in Levinson and Turner's research believed that science teaching should be about the delivery of facts and must avoid values, opinions or ethics. Wellington and Ireson (2012) argued that including controversial issues in the curriculum is essential if the true nature of science is to be conveyed to students.

Which side of the argument do you agree with and why? One of the difficulties teachers have cited is in identifying clear objectives and outcomes for students and matching these to learning outcomes.

Activity 10 Teaching controversial issues

Allow about 20 minutes

Resource 1 provides some of the objectives and outcomes associated with teaching controversial issues and possible teaching approaches. Identify which learning outcomes could be achieved by each approach.

Different approaches support the different student outcomes. Teachers need to consider many factors when selecting an approach, but should be able to justify their choice and identify appropriate, achievable objectives and outcomes.

4.3 Taking a stance

As well as deciding on the approach to be taken, teachers need to consider the 'stance' or role that they will take. There is a legal requirement that teachers must present a balanced view when dealing with controversial issues. It is not acceptable for teachers to indoctrinate students with their views or support prejudiced stances or racist or sexist views. So what options are open to teachers?

Activity 11 Taking a stance

Allow about 20 minutes

The stances that a teacher could adopt when teaching a controversial issue are given in Resource 1. What are the problems, challenges or potential pitfalls with each stance? What are the advantages and disadvantages of each stance from the teacher and students' perspectives?

When deciding which stance to take, the teacher needs to consider that they are in a more powerful position than students, and that some stances may reduce the students' autonomy. The teacher also needs to consider the impact on students' interest and motivation, how easy it will be to prepare for the lesson, and how easy or difficult it will be to adopt and keep up through the lesson.

4.4 Teaching controversial issues

One of the reasons why teachers may be reluctant to engage students in controversial issues is finding suitable resources that students will be able to access. However, there is a plethora of resources produced by various organisations aimed at students available on the internet.

Of course, teachers need to be aware of the bias in such resources. It is not possible to avoid such bias – it's a human trait – but it doesn't mean that resources produced by organisations with a vested interest or a particular view should be avoided. It is important, however, that this bias is considered and brought to students' attention. Ideally, students should be provided with material that presents the other side of the argument. Approach A in Resource 1 is one way in which bias can be dealt with.

As a teacher of science you are navigating a potential moral and ethical minefield. Dealing with emotive and controversial issues requires time for research and preparation, well-developed personal knowledge of the issues and knowledge of appropriate teaching pedagogies. The teacher also needs self-confidence, positive working relationships with students and good classroom discipline. Some teachers may fear upsetting students or worry that they might be seen as indoctrinating students, so knowing how to approach teaching controversial issues and thorough planning are essential. There is also the question of assessment of such complex skills in a climate of accountability and record-keeping.

It is not surprising that many science teachers feel underprepared and lack confidence in dealing with ethical and social issues in science (Levinson and Turner, 2001). However, this is not a reason for omitting controversial issues from the curriculum. To do so does students a disservice, depriving them of an understanding of the realities of science and its impact on people and the environment.

Activity 12 Planning and teaching a controversial issue

Allow about 2 hours

Identify an opportunity to incorporate a controversial issue in your science teaching. Use the ideas in this section of the course to plan your approach and the stance you will take.

Collect student feedback on the extent they engaged and enjoyed the lesson, and what they learned.

Conclusion

In this free course, *Teaching secondary science*, you have looked at the images and conceptions of science, and how these impact on school science education. Teachers need to have these views in mind and employ strategies to make science accessible and appealing to all. This involves teaching students about the nature of science through purposefully designed activities, as well as taking opportunities presented through practical work. Above all, teachers must consider what students will learn through practical activity and be aware of the hidden messages that might be inadvertently communicated. By engaging with the stories and lives of past scientists, as well as the controversial science issues affecting society, science can be brought to life as a human endeavour that has relevance and meaning for them and their future.

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Further reading

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Figures

Figure 1: Burnard, P. (1996) *Acquiring Interpersonal Skills: a Handbook of Experiential Learning for Health Professionals*, 2nd edn, London, Chapman & Hall.

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