CHAPTER 5: TEACHING CONTROVERSIAL ISSUES IN SCIENCE

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Introduction

Discussion of controversial issues is at the heart of responsible action in democratic societies. It is how young people acquire the knowledge and skills for critical thinking which strengthens democratic deliberation. This chapter will therefore focus on what is meant by controversial issues in science, how How Science Works underpins the teaching of controversial issues and what kinds of pedagogy and resources can best support discussion.

In recent years there has been increasing emphasis on the teaching of controversial socio-scientific issues reflecting debates on matters such as GM crops, stem cell research, radiation from mobile phones, cloning and use of pesticides on crops. The report, *Beyond 2000*, which was instrumental in setting the agenda for reforms in science education in England. reflects these shifts: 'For the majority of young people, the 5-16 science curriculum . . . must provide both a good basis for lifelong learning and a preparation for life in a modern democracy. . . ' (Millar and Osborne, 1998, p. 2009).

Democratic participation for the future citizen is therefore an important feature of the case made for including controversial issues in the science curriculum, reinforced through aspects of the programme of study in the citizenship curriculum.

In this chapter I will:

- examine what is meant by a controversial issue;
- discuss why the pedagogic demands for teaching socio-scientific issues are different from those in substantive school science;
- identify the kinds of knowledge and skills needed for discussing controversial socio-scientific issues;
- explore the classroom opportunities for examining socio-scientific issues (SSI) within the context of How Science Works.

What are controversial issues?

The straightforward answer to this question is that controversial issues are matters which people disagree about ranging from what to watch on television, whether the classification of the drug ecstasy be downgraded, and should Britain have troops in Afghanistan. Almost everything people do and talk about can be considered controversial. So what are the characteristics of controversial issues that might be appropriate for teaching in the classroom? The depiction of what is a controversial issue through the advisory report on Citizenship should be a helpful pointer. A controversial issue is one, 'about which there is no one fixed or universally held point of view. Such issues are those which commonly divide society and for which significant groups offer conflicting explanations and solutions.' (Crick, 1998, p.56)

Because controversial issues 'are those which commonly divide society' this takes any definition beyond local individual differences such as arguments in a family or between friends over what to watch on television. But there are many issues which commonly divide society such as which is the best football team in the U.K., who should win TV shows such as X-Factor, should taxes be raised to help reduce carbon emissions. It is likely that a greater number of people are more passionately divided, and can offer good justifications, about who wins TV game shows than about many local or national policy issues, but it would be difficult to make a case for them to constitute a significant portion of the school curriculum.

Teachers and curriculum designers need to know the skills and knowledge which would be helpful in justifying the place of controversial issues in the curriculum. Dearden proposes an epistemic criterion of a controversial issue – 'a matter is controversial if contrary views can be held on it without these views being contrary to reason' (Dearden, 1981, p.38). Reason within this definition refers to criteria of truth, critical standards of verification which at any given time have been so far developed. ‘What is controversial’, argues Dearden, is ‘precisely the truth, correctness or rightness of view, which presupposes that at least it makes sense to search for these things even if we do not attain them’. (Dearden, 1981, p.40). Hence, not only are controversial issues matters over which large sectors of an open and democratic society disagree but they presuppose rigorous justifications supporting diverse points of view where there is no necessary agreement over the criteria for judging what is correct or not. The emphasis is not on content but on the reasoning and underpinning dispositions such as criticality, openness and willingness to listen which support rational discussion (Bridges, 1979).

Given the diverse types of disagreement possible in society from those which might be easily resolved to those which divide people on deep-seated beliefs, McLaughlin (McLaughlin, 2003) devised a categorization based on the work of Dearden and other philosophers which Levinson (Levinson, 2006) formulated in terms of levels of disagreement and the role of evidence in socio-scientific issues. Selected features of this categorization are listed in Table 5.1.

<Insert Table 5.1 here>

Table 5.1 demonstrates there are different ways in which disagreements can be formulated and highlights the distinct role of evidence. Issues such as climate change, introduction of nanotechnologies and the effects of the new genetics are so complex and multi-faceted it would be far too demanding to cover them satisfactorily within the constraints of the curriculum but it is possible to identify the specific social and epistemic nature of disagreements within the overall controversy. The teaching points to be gleaned from this table are to identify particular aspects of an issue, to explain why they are controversial and to develop an approach which seeks to investigate the controversy further.

In Level of Disagreement 1, parties on different sides of an argument will accept that a disagreement is settled one way or the other by evidence. Such an approach can be illustrated in making a prediction and seeing if the evidence does or does not support the prediction. A simple but effective example was illustrated by a beginning teacher I was observing who, in a lesson on healthy eating, asked the students in her class to pour into a beaker the estimated amount of daily intake of salt recommended without using balances. There was a lively discussion and disagreement about what might be the right amount and groups differed by a factor of 100. When the amounts from the groups were weighed there was considerable shock when most realized how small the daily intake really should be. The point is that the evidence was incontrovertible and once it had been demonstrated disagreements were resolved.

Similar activities can be carried out for example in predicting how current will be affected when changing a circuit, the rate of cooling of different liquids, the relative amounts of oxygen evolved by plants in different conditions and predicted rates of reaction. But few socio-scientific issues are resolved so definitively.

Teaching socio-scientific issues

Particular demands are placed on teaching socio-scientific issues in science and it is not surprising that science teachers have found them stimulating but difficult to deal with (Bryce and Gray, 2004; Levinson and Turner, 2001). Science as learned and experienced in school presents quite different pedagogical challenges from those incorporated in controversial socio-scientific issues (see Table 5.2) because in the latter, knowledge is used to try and solve socio-political, ethical and economic problems whereas much school science revolves around the core principles of authoritative science which do not lend themselves to solving such problems (Layton, 1986; Ryder, 2001). Although science has been characterized as both progressive and provisional in nature (Chalmers, 1999; Popper, 1972) much of the science taught at school is authoritative and universally accepted. At secondary school level, knowledge of the Periodic Table of Elements, Newton's Laws of Motion, the Laws of Thermodynamics, Krebs Cycle and the processes of photosynthesis is beyond reasonable question, let alone the orbits of the planets around the Sun, and Earth as a spheroid (Flat Earth Society excepted!). It would be strange for a student to complete studying science at age 16 thinking that the atomic number of hydrogen still had to be determined, that the Laws of Motion were tentative statements and that it was only true today that green plants incorporate carbon dioxide and water to build up more complex organic molecules. But the science in many contemporary issues – climate change is an obvious case – has a very different basis. While there is some consensus among experts, much ‘frontier science’ is still disputed (Bauer, 1997), experts generate conflicting models, data are uncertain and interpretation of even agreed data differs. Knowledge in contemporary socio-scientific issues such as genetic technologies, nanotechnology as well as climate change is therefore emergent and tentative whereas substantive science knowledge is seen as authoritative and certain.

It follows that school science knowledge is broadly uncontentious whereas contemporary science in socio-scientific issues is often conflicting, both among scientists and many non-scientists too. But this difference suggests a link which can be made between traditional school science and ‘frontier’ science. Scientific theories, such as the great cosmological theories, the oxygen theory of combustion, circulation of the blood and Natural Selection, were themselves strongly contested historically, and a study of the processes through which knowledge progresses from the tentative to the accepted can begin to give insights into disputed knowledge around the science behind contemporary socio-scientific issues. For example, students can readily appreciate why people might have believed the Earth was flat, that the Sun revolved around the Earth and that some indefinable substance escaped from fuels when they burned. Caution needs to be exerted here because the epistemic and social factors are historically contingent. To teach, for example, the conceptual basis of phlogiston theory or the complex mathematics in Newtonian mechanics, or the differences between the ways in which science is organized at a global level today compared with the seventeenth century would be too demanding and unnecessary, but any study of change of status in scientific thought will help students to understand that ideas can be both intellectually sound but also provisional.

As suggested above the pedagogic implications are considerable. Science as learned and experienced in schools is predominantly deductive, involving the illustration and amplification of theory. Examples are experiments on pendulum motion, combustion of magnesium both to demonstrate gain in mass and combination of masses, pasteurization and so on. Some of the examples in argumentation (see Chapter 6) help to provide evidence for dominant scientific concepts which contrast with classical and early medieval thought such that light scattered from a luminous source enters the eye rather than eyes actively emitting light rays to illuminate objects (Osborne et al., 2001). While secondary students are unlikely to formulate new hypotheses and theories they can interpret and get beneath the skin of scientific ideas by trying to grapple with and explain original ideas (Sutton, 1992). In fact, school science can generate new and exciting insights and problematize authoritative science. Erasto Mpemba, a Tanzanian school boy in the 1960s, is a wonderful example of how school science can provide convincing evidence to question even well-established laws. He showed how the cooling of an ice cream mix in a freezer can seemingly contradict the laws of thermodynamics through a phenomenon now known as the Mpemba Effect (Jeng, 1998)

Donnelly (Donnelly, 2004) has argued that many of the core concepts in school science are reductionist and instrumental and free from the kinds of human considerations that feature in arts, humanities and even the social sciences. Entities such as electromagnetic fields and molecules behave very differently to the often serendipitous nature of humans. How they respond to certain stimuli are predictable and follow clear patterns and scientific laws, in other words, they are linear. Even then in science causal relationships are predictable only to a certain level of complexity as seen for example in chaos theory. In socio-scientific issues the science is often complex and bears little relationship to school science (Thomas, 2000). Moreover the science cannot be easily disentangled from its social effects. Where science has an impact on society, those involved have to take into account people's beliefs, experiences, cultural understandings, everyday practices and emotions. Values and human concerns feature predominantly in discussions of and decision-making in socio-scientific issues.

Such values might include ethical aspects of the introduction of a technology but also the kinds of values which support the introduction of a technology in the first place, for example, why so many more medicines have been synthesized for coronary heart disease than in eradicating malaria. Or there are considerations which might affect one's everyday life such as whether it is acceptable to vaccinate a child given certain risks involved. How decision-making takes place around these issues also involves political skills, knowledge and understanding. Much contemporary R&D is initiated through corporations and government. How decisions are taken as to what is developed, regulated, and how people have a say in their impacts are not straightforward: they depend on democratic processes, scientists' relationships with interested parties, how knowledge about the technical processes is communicated, trust in regulators and so forth (Irwin and Michael, 2003).

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What do students need to know

If what is learned in school science is so different from socio-scientific issues what kind of knowledge and pedagogy is appropriate? Here are a few examples:

A. A young couple who would like to have a baby suspect they are both genetic carriers for cystic fibrosis (CF), which is confirmed when they seek the advice of a genetic counsellor. What do they need to know about genetics to help make a decision? What kind of science ought the counsellor to tell the couple? Which other factors do they need to take into account to help make a decision?

B. A group of residents in a village have been feeling unwell and displaying a range of symptoms since a mobile phone base station was erected nearby. Doctors are mystified as to the cause of the symptoms but they are sure that the incidence of ill-health is much greater than expected from a similar population. A meeting is arranged with engineers from a mobile phone company.

C. Recent surveys of global public opinion reveal that two thirds of those surveyed saw climate change as a 'very serious problem.' This might seem a very promising statistic but is it of greater concern that nearly a third do not? Furthermore even those who were concerned about climate change did not see a link between burning of fossil fuels and the effects on climate (BBC World Service, 2009, on-line). Climate change activists consider a strategy to influence public opinion.

A number of points emerge from these three examples. First the conceptual science content is very different. Example A involves a basic understanding of genetics and inheritance and the probability of two carriers having an affected child. But just as importantly it involves questions about the rights and wrongs of having a child when there is a high chance it will have CF, the effects on other family members, the availability of care, the possibilities of cure, the increase in average longevity of CF sufferers, the costs of bringing up a child with genetic health problems, the psychological effects on child and parents, and of course the consequences of the couple deciding not to have children. In example B some understanding is required of intensity of radiation, wavelength, frequency, whether radiation is ionizing or not, understanding of the differences between correlation and cause, sample size, cluster effects, as well as the ability to engage in dialogue with company representatives and understanding what political recourses might be available. Example A involved a couple and their immediate family whereas example B involves a group of concerned people and a range of social, political and environmental factors. Examples A and B are relatively local, example C is global in range and the science will be derived from a number of specialisms: geoengineering, meteorology, physical chemistry. Rhetoric and political clout, knowing how to communicate research sensitively and compellingly, as well as distinguishing between science which is relatively certain and science which is highly uncertain, an understanding of trust and the precautionary principle will be equally important.

While a basic knowledge of the underpinning scientific concepts is crucial to orient the issue the predominant factors are personal, ethical, financial, medical, and include some understanding of risk.

Ryder (2002) carried out a survey of studies of a range of socio-scientific issues reported in the research literature and the substantive science needed to be able to act in these circumstances. His research revealed five different learning aims to support decision-making in the contexts of these issues. These are:

- an ability to assess the quality of data, for example, to appreciate that measurements are inherently variable and that from a set of data students need to understand that there is no true value but a spread of measurements from which an estimate of variability can be obtained;
- the design of a study will influence the kind of data obtained, for example whether double-blind studies have been carried out and placebos administered in medical interventions, the sample size studied, and the differences between correlations and causal relationships;
- scientific explanations and the role of models;
- uncertainty in that many socio-scientific questions are complex, consisting of uneven and interdependent variables and do not yield unequivocal answers;
- an understanding of the media through which science is communicated and that aspects of reliability and validity of measurements are often excluded from media reports.

Arising from these aims Ryder suggests teaching strategies which are more suited to decision-making in socio-scientific activities. One of these in an understanding of the use and interpretation of secondary data, the kind of complex data which it would be impossible to collect in science lessons. A problem, however, in interpreting secondary data is that this data itself as reported in specialized journals often uses complex sampling frames and statistical techniques which most teachers, let alone students, would understandably lack the knowledge and experience to interpret. While some data will be accessible to students at this level, another way of approaching the use of data is to incorporate data such as narratives of experience and ask students what kind of data would be helpful in trying to resolve a particular issue. In the next sections I will try and exemplify how students might construct informed arguments through two examples.

Sunbeds – 'as long as you don't use the sunbed too much I'm sure you'll be fine'.

In this example, in terms of How Science Works I will be drawing on how scientific data can be collected and analysed, the limitations of data, the benefits, drawbacks and risks of scientific and technological developments, and the social impacts of decision-making.

One of the main health concerns for young people is the risk of skin cancer from ultra-violet radiation, although there are benefits of a tanned skin and the production of Vitamin D. Deficiency of vitamin D can result in bone-softening conditions, rickets in young children and lead to osteoporosis in later life. But lack of vitamin D can be made up through food supplements as well as through exposure to sunlight and artificial sources of UV radiation.

In less sunny climates such as northern Europe and North America many young people resort to tanning parlours and sunbeds as a way of producing ‘healthy tans’ which give a feelgood factor. Everyone is exposed to ultraviolet radiation because it is among the spectrum of electromagnetic wavelengths emitted by the Sun. Wavelengths of ultraviolet radiation are between 100-400nm: there are three types of ultraviolet radiation, UV-A, UV-B and UV-C, where UV-A has the longest wavelength and is least damaging to the skin and UV-C has the lowest wavelength and is most penetrating to the skin. Most UV-C radiation is absorbed by the ozone layer before it can enter the Earth’s atmosphere. UV radiation can damage DNA in the cells resulting in skin cancer. People with fair skin are most susceptible to skin damage from UV radiation whereas people with dark or black skin are at much lower risk and can withstand much higher levels of intensity of exposure.

Until 2009, health authorities suggested that there was a probable link between the use of sunbeds and cases of malignant melanoma, one of the deadliest forms of skin cancer but now the International Agency for Research on Cancer says that use of sunbeds is definitely ‘carcinogenic to humans’ (BBC News, 2009, on-line). The risk of malignant melanoma is increased by 75% for people who start using sunbeds regularly under the age of 30. Cancer Research UK states that 'Using a sunbed once a month or more can increase your risk of skin cancer by more than half. So when the tan fades, the damage remains' (Cancer Research UK, 2010, on-line). Not only do Cancer Research UK claim it is a cultural myth that tanned people have a healthy appearance but they emphasize that tanning is a sign of damaged skin which will wrinkle and become unsightly with increasing age. The problem seems to have become worse in recent years because high power sunlamps are now available in tanning parlours which exceed the legal safe dose for UV radiation and in mimicking effects from the Sun, emit UV-B as well as UV-A. From December 2009 it became illegal for under-18s to use sunbeds in Scotland.

Unsurprisingly, these findings, conclusions and warnings are strongly disputed by the Sunbed Association. They argue that scientific research shows that people exposed to UV-B have a *lower* risk of contracting malignant melanoma, provided sunbeds are used moderately, Moderate use of sunbeds appears to have health benefits: it promotes a feeling of well-being; it protects against too much exposure to the sun because pre-tanned people are unlikely to lie for prolonged periods in the sun to generate a tan, tanned skin in fact protects against sunburn and has a benefit in the production of Vitamin D. The Sunbed Association further claims that by far the largest number of users of sunbeds do not exceed the European Standards on maximum numbers of sessions per year, hence people using properly regulated tanning salons, or using their own sunbeds within prescribed limits, should be exposed to minimum risk. No amount of legislation can stop people using unregulated salons (The Sunbed Association, 2010, on-line).

The Sunbed industry argues that medical and health authorities such as Cancer Research UK through its Sunsmart campaign, would do better to lobby for safe and moderate use of sunbeds, and that there should be much more emphasis on safe outdoor exposure. Moreover they questioned both the validity and the reliability of the studies in that they made no reference to scientific research which indicates there is *no* link between sunbed tanning and melanoma. They argue that rise in melanomas is not a result of increased use of sunbeds but better diagnosis, so while there is a correlation, it would be wrong to assume there is a causal relationship, and this is further evidenced by the fact that there has been no corresponding increase in mortality, i.e. the number of deaths in a population sample, from skin cancer.

Whether sunbeds should be banned or not is therefore a controversial issue because there are reasons both in support of banning the use of sunbeds for under-18s and in opposing this type of regulation.

Does the evidence support or refute the decision to ban the use of sunbeds for under-18s?

In starting to answer this question it becomes clear that the evidence is complex, conflicting and difficult to assess but that does not mean students cannot make a decision based on the evidence. The evidence is complex because these studies are sophisticated, often involving difficult statistics, and on their own the data is likely to be too complex for Key Stage 4 students to interpret. The evidence is conflicting because data has been gathered on both sides of the question which supports opposite points of view and it is difficult to assess because the sunbed industry claims that selection of research is partial and does not present the whole picture. A report on the British Medical Association's website, dated 22nd November 2007, says:

> 'Westerdahl found that regular exposure to sunbeds significantly increased the risk of developing malignant melanoma. However, a recent large-scale study has found that there was little or no increased melanoma risk associated with sunbed use. A review of the epidemiological evidence shows that 16 out of 19 case-control studies found no association between tanning lamps and melanoma. Three found a significant positive association and consistent but not strong evidence suggesting that exposure at a younger age may give rise to a greater risk. The authors concluded that methodological limitations of the studies preclude reaching a firm conclusion regarding causation. Therefore new studies collecting precise exposure data are urgently needed.'

How then are young people able to glean the knowledge and skills necessary to make sense of the arguments so they can make a reasoned decision based on a consideration of different points of view. One way forward is to identify the claims by organisations on opposing sides of the argument and subject them to critical analysis. While students are likely to attain different levels of critical analysis, depending on their background knowledge and level of attainment, both the reported data and the media presentation lend themselves to How Science Works skills.

A first consideration is to help students understand the statement from Cancer Research U.K. that ‘Using a sunbed once a month or more can increase your risk of skin cancer by more than half.’ ‘Risk’ is now a concept incorporated in Ideas About Science and in How Science Works. But unlike many scientific terms such as ‘force’ or ‘potential difference’ its meaning is imprecise and it can be interpreted even among scientific organisations in many different ways. Risk is commonly understood to refer to the probability of an event combined with its impact. So what does the statement from Cancer Research UK mean?

- Does it mean that if you have a 50% chance of getting skin cancer without using a sunbed more than once a month you will have a 75% chance of getting skin cancer if you do use a sunbed more than once a month? Or if you have, say, a 0.01% chance of getting skin cancer without using a sunbed your chance will rise to at least 0.015% if you do?

- If 200 people out of a population of 50 million die from skin cancer in a certain period of time then if all those people were using sunbeds the figure would rise to 300 people?
- Does an increase of risk of 50% mean increases in numbers of deaths of 1 person per year out of a million people or 100 or a 1000 deaths?
- How would people react if the statement said that your risk of developing skin cancer would be reduced by 25% in relation to those who do use sunbeds more than once a month?
- If 9000 new cases of melanoma are reported each year and we assume that 5% of the population of 50 million use sunbeds more than once a month, how many of these cases might be due to sunbed use?
- How might the stated risks compare with those whose life expectancy is shortened by consuming three pints of beer every week?

How, for example, do estimates of relative risk compare with those of absolute risk? If the numbers affected are small to begin with then a 50% rise might not seem very serious; if they are large then the seriousness will be much greater. One way to approach this problem is to encourage students to experiment with this data in different way: how might they represent it visually? Students could experiment using pictograms, bar charts or represent information in percentages. Asking students to represent information as in, say, a popular newspaper, would help to reinforce understanding of how information can be interpreted differently depending on context (Jarman and McClune, 2007).

A further way of analyzing the arguments is for students to read relevant extracts from the websites of Cancer Research UK and from the Sunbed Association where they can pick out sentences which support or challenge the case for a ban on using sunbeds for under-18s A format for doing this derived from Wellington and Osborne (2001) is:

- extract sentences which contain statements containing evidence for or against the banning of sunbeds;
- identify the *source* of the evidence used to justify the claim (as well as any raw data, this might include references to authoritative sources and why the students might trust or distrust those sources);
- justify to what extent the evidence justifies or contradicts the ban
- weigh the evidence on both sides: would they support or challenge a ban?

If, as may be likely, they felt there was not enough information to make a decision, what kind of information would be required and how might it be gathered?

Bioinformation and personal privacy – 'if you're innocent what have you got to worry about?'

In the scenario on sunbeds the focus of the activity was on interpreting and weighing evidence. In the scenario on bioinformation, the focus is on the application and implications of science and accompanying ethical issues, i.e. levels of disagreement 8 and 9.

Bioinformation is a means of identifying a person from an analysis of unique characteristics such as fingerprints or DNA. With huge advances in the last twenty years in DNA technology it is now possible to identify people from traces of DNA left, for example, at a crime scene. DNA can be extracted from blood (although not red blood cells), layers of skin and semen left behind at a crime scene. This has been made possible by the development of new techniques for rapidly amplifying DNA and separating small fragments to give unique identifiers. This information is now stored on a national database.

Forensic use of DNA has very clear benefits. In 2009, a man who had served nearly thirty years in jail for the murder of Teresa de Simone was released because DNA evidence showed that he could not have been the murderer. A DNA sample taken from the body of a suspected man who had killed himself twenty years ago showed a clear match to DNA found on the body of the murder victim. There are many instances of people being convicted – and cleared – of crimes when no other type of evidence is available and therefore DNA evidence has become a valuable technique.

There is now a national DNA database in which DNA information is held for all people who have been convicted of a crime, or who have had DNA samples taken when they have been arrested or suspected of a crime even if they have been found not guilty. The application of this technology therefore raises a number of ethical questions. First, while the technology is highly developed, it does depend on correct samples being taken and not contaminated with other DNA which might incriminate perfectly innocent people. Secondly it has raised a more general question about civil liberties. If everyone contributed DNA samples to a national data base it would make it possible to eliminate suspects from a crime very quickly and identify the perpetrator. While DNA profiling is very reliable, there is the chance that the DNA at a crime scene might be collected incorrectly and tarnish the reputation of an innocent person. There is also the possibility that DNA from the database could be misused, given away without the individual's consent and possibly be very dangerous evidence against innocent people when in the wrong hands. For example, research has been done on correlating DNA with ethnic identity.

One argument has been ‘if you’re innocent what have you got to worry about?’ But there is some uncertainty in identifying people from DNA and there have been occasions when experts have disagreed about whether the DNA profile constitutes sufficient evidence. There is a core argument about the importance of civil liberties. For some people, protection of civil liberties takes priority over catching some criminals whereas for others personal and national safety is more important. There are, therefore, questions on the applications of science and technology about which people’s judgments might differ based on their core values.

Once students have some understanding that DNA is unique (except in identical twins), and how it might be amplified and profiled they will have sufficient background to engage with the question as to whether a national database should include all people (possibly even children).

One popular approach is to take a ‘vox pop’ or estimate of agreement or disagreement before any discussion takes place. This can be done by a quick hand count, or asking students to arrange themselves from one end of the room to another depending on how far they agree or disagree with the question. Sometimes, the problem with this approach is that students haven’t really thought about the issue at all and so any response can be arbitrary. The question can be put in a more focused and immediate way so it has personal relevance, e.g. would you be happy for your DNA to be put on a national database given that it might be misused in the future and used against you?

Another way to present the question is through a range of differing opinions or concept cartoons (Keogh and Naylor, 1999). For example:

'I think people's rights to protection against crime are more important than their rights to privacy.'

'Having a national database might turn us into a police state'

'My biological information should be my property and nobody else's.'

'DNA evidence isn't 100% safe so we shouldn't use it.'

In the statement 'My biological information should be my property and nobody else's' an opposing argument is to cite cases where bioinformation is kept for perfectly good reasons such as doctors keeping medical records. There is also a more fundamental question as to why an individual should have any more right to their bioinformation than anyone else. On the other hand, supporting evidence could provide evidence where use of bioinformation has been mishandled.

Another strategy to support critical thinking in a discussion is to ask a group of students (group A) who are very committed to a point of view to state their viewpoint as clearly as possible in three minutes. They are not allowed to be interrupted and must not overrun their time. When they have finished a group of students (group B) with opposing points of view must then repeat the same argument and, if anything, provide a stronger case than group A. After that, group B give their point of view and group A similarly have to repeat their argument. This shows that students have listened carefully to each other and understand the arguments. After that the topic can be opened to questioning.

In discussing issues where there is no clear answer students often resort to a tactic of 'that's just my opinion, take it or leave it' which simply ends a discussion. To make the discussion more fruitful it is important that the teacher can prompt the student to reason and explain their point of view without influencing the argument. This means understanding, and being prepared, with a range of different arguments. Useful resources for this are the reports on DNA profiling from Gene Watch UK and Nuffield Council on Bioethics.

In many controversial issues of this kind there is no unequivocal answer. There are always further questions which can be raised. For example, students might be willing to allow some constraints on their liberty if they know how reliable DNA technology is, how it is stored, how information is accessed, and who can use it. The point here is not necessarily to resolve the issue but to help students think more deeply about it.

Concluding comments

In this article I have argued that controversial issues are usually complex and need to be broken down into different levels of controversy if there is to be productive discussion and students are enabled to engage and deepen their understanding of How Science Works. For science teachers, and for teachers generally, this is a tough task because controversial issues in science look very different to much of the science done on a day to day basis. Students can therefore be inducted gradually into the more open and messy area of controversial issues, for example, by looking at the role of evidence in making simple predictions, then exploring areas in which the evidence is much more complicated and finally into the kinds of arguments which cannot be decided on evidence alone, or where evidence consists of more than numerical measurements such as narrative accounts and experiences. Even in relatively simple ways of using evidence students can begin to appreciate its complexity. There are intrinsic errors involved in reading even familiar instruments like temperature on a thermometer, length of a measuring tape and volume on a measuring cylinder. Asking students to measure the temperature of a beaker of water at room temperature will generate values and offer opportunities for discussion on the reliability and variability of any measurement. If students can begin to understand these constraints they are more likely to appreciate the complexity and care in drawing conclusions on controversial socio-scientific issues.

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