Learning to teach controversial topics

Michael J. Reiss

Abstract

Controversial topics can be used in school science teaching to help students gain a better understanding of how scientific knowledge is built up, and of the contributions of other disciplines, such as ethics and economics, to real-world socio-scientific problems. A narrow definition states that a topic is only controversial if alternative positions can be held without those views being contrary to reason. A broader definition states that a topic is controversial if it is topical, if there are conflicting values, opinions and interests, if emotions may become strongly aroused and if the subject/area is complex. Topics may be controversial because the basic science is uncertain or for other reasons. There are different ways of teaching controversial issues in science classrooms and each has advantages and disadvantages. The chapter concludes by considering how three controversial topics – evolution, climate change and vaccines – might each be taught.

Reiss, M. J. (2022) Learning to teach controversial topics. In: Handbook of Research on Science Teacher Education, Luft, J. A. & Jones, M. G. (Eds), Routledge, New York, pp. 403-413. DOI: 10.4324/9781003098478-36.

The value of controversial issues in the teaching of science

There are several arguments that can be advanced as to why controversial issues (or topics) should be taught in school science. For a start, some issues are controversial because the science is not yet clear (Wellington, 1986). Teaching them can therefore help students to appreciate that science is not always about certainties. A recent example was the question of whether wearing masks reduced the transmission of COVID-19. Because COVID-19 only arose towards the very end of 2019, this question was being asked (in the spring and summer of 2020) before careful empirical work had been undertaken to address the issue.

A second reason for teaching controversial issues in science is that this can be motivating for students (Yuliastini et al., 2018). Different students may be motivated by different approaches to teaching but many students enjoy thinking about and discussing issues where the answer is not clear-cut and where there are genuine differences of opinion.

A third reason overlaps with the first two and that is that many contemporary problems in society where science plays a part are ‘wicked’ in the sense that they cannot be solved straightforwardly. The term ‘wicked problem’ was introduced by Horst Rittel and its most well-known formulation was produced by Rittel and Webber (1973):

> The search for scientific bases for confronting problems of social policy is bound to fail, because of the nature of these problems. They are “wicked” problems, whereas science has developed to deal with “tame” problems. Policy problems cannot be definitively described. Moreover, in a pluralistic society there is nothing like the undisputable public good; there is no objective definition of equity; policies that respond to social problems cannot be meaningfully correct or false; and it makes no sense to talk about “optimal solutions” to social problems unless severe qualifications are imposed first. Even worse, there are no “solutions” in the sense of definitive and objective answers.
>
> (Rittel & Webber, 1973, p. 155)

Examples of ‘wicked problems’ that might be discussed in school science include many ecological issues (such as tackling the loss of biodiversity in an area), many health issues (such as the 'causes' of obesity), and issues to do with energy generation (such as whether wind power is better than gas-fired power stations for electricity production).

What is a controversial issue?

Much of the academic literature in education on controversial issues start with the work of Dearden, who proposed an *epistemic* criterion in which "a matter is controversial if contrary views can be held on it without those views being contrary to reason" (Dearden, 1981/1984, p. 86). Dearden pointed out that several possible kinds of controversial issue may be distinguished: "cases where we simply have insufficient evidence to settle the matter, though in principle there is no reason why it should not be settled as more or better evidence becomes available … where consideration-making criteria are agreed but the weight to be given them is not … where there is no agreement even on the criteria as to what will count" (p. 86) and, finally, "where not just individual criteria but whole frameworks of understanding are different" (p. 87).

A large literature in education on controversial issues has grown in the light of Dearden's argument (e.g., Bridges, 1986; McLaughlin, 2003; Hand 2008). Michael Hand (2008), in particular, has defended and developed Dearden's epistemic account, arguing that "What distinguishes teaching-as-settled from teaching-as-controversial (or directive from nondirective teaching) is not a pedagogical method or style, but the willingness of the teacher to endorse one view on a matter as the right one" (Hand, 2008, p. 213). Hand is explicit that "The English word 'controversial' means simply 'disputed', and the existence of dispute is an unpromising criterion for what should be taught nondirectively" (p. 214).

However, the epistemic identification of the controversial is not the only one (e.g., Wellington, 1986; Hess, 2009). The opening chapter of the book *The challenge of teaching controversial issues* states:

> In general terms a controversial issue is one in which
> - the subject/area is of topical interest
> - there are conflicting values and opinions

- there are conflicting priorities and material interests
- emotions may become strongly aroused
- the subject/area is complex.

(Claire & Holden, 2007, pp. 5-6)

This is a much broader definition that that provided by Dearden. It is also much more in line with how the phrase 'controversial issue' is understood by most people, including school students.

Controversial issues in science education

A detailed conceptual analysis of controversial issues in science education is provided by Levinson (2006). Levinson used McLaughlin's (2003) classification of controversial issues into nine categories of reasonable disagreement and extended these to school science:

1. Where insufficient evidence is as yet available to settle a matter, but where such evidence could in principle be forthcoming at some point.
2. Where evidence relevant to settling a matter is conflicting, complex and difficult to assess.
3. Where the range of criteria relevant for judging a matter are agreed, but the relevant weight to be given to different criteria in a given decision is disputed.
4. Where a range of cherished goods cannot simultaneously be realised, and where there is a lack of a clear answer about the grounds on which priorities can be set and adjustments made.
5. Where the range of criteria relevant for judging a matter are broadly agreed, but there is dispute about the proper interpretation of a criterion or criteria, given the indeterminacy of many concepts,
6. Where there are different kinds of normative consideration of different force on both sides of an issue, and it is hard to make an overall judgement.
7. Where there is disagreement about the criteria relevant for judgement.
8. Where the differing 'total experiences' of people in the course of their lives shapes their judgements in divergent ways.

9. Where there is no agreement about whole frameworks of understanding relevant for judgement.

An example of category 1 would be whether a particular individual is likely to develop Huntington's disease which, as Levinson points out, could be settled by an unambiguous genetic test. An example, at the other end of the spectrum, of category 9 would be "Fundamentalist creationists work from different premises and use different truth criteria from evolutionists to establish their claims" (Levinson, 2006, p. 1212). An evolutionist bases their conclusions on scientific evidence (involving the dating of fossils, biogeography, molecular genetics and so on) interpreted within an evolutionary paradigm (dating from the work of Darwin and Wallace, and informed by the subsequent contributions of Mendel and others), whereas the first line of authority for a fundamentalist creationist is the scriptures of their religion, typically backed up by a history within their community as to how those scriptures are interpreted.

As Zeidler and Sadler (2008) point out, socio-scientific issues (SSI) may, by their nature, be controversial but (as Levinson pointed out above), the converse is not necessarily the case. Zeidler and Sadler go on to maintain that "SSI tend to have implicit and explicit ethical components and require some degree of moral reasoning" (p. 800). One reason why SSI are controversial is precisely because humanity simply does not have a single widely agreed moral framework within which ethical conclusions can be agreed.

In common with the majority of the literature, and in the light of the above, this chapter therefore adopts a broad understanding of 'controversial' and examines the different sorts of controversies that arise in science education. Consider, for example, whether the theory of evolution, a well-established scientific theory, is a controversial issue. As the classification of Levinson above makes clear, the theory of evolution is not controversial in the sense that the genetic modification of organisms is – where the controversy is not over the basic science but over whether we should or should not genetically modify organisms. In terms of science, rather than ethics, the consequences of anthropogenic climate change might be deemed controversial, at least in part on the grounds that there is much that we genuinely don't know about these consequences, but this is not what is meant by the theory of evolution being controversial. Although, as with any science, there is uncertainty at the edges of the science, the core ideas of evolution have been well-established within the science for many decades.

Among the overwhelming majority of scientists, the theory of evolution is nowadays no more scientifically controversial than is the Periodic Table, quantum dynamics or plate tectonics. So, evolution is not a controversial issue on the epistemic understanding of controversy. But we all know of the furor that regularly surrounds it in many countries (Deniz & Borgerding, 2018) in the courts, in the media and in schools – it is controversial in the broader sense of the term.

How might one teach about controversial issues in science education?

Three approaches as to how controversial issues might be taught in school science were developed by Reiss (1993) from Bridges (1986). One is the approach of *advocacy*, where the teacher argues for the position they hold. For example, one teacher might assert 'There is no such thing as animal rights; only humans have rights'; another might assert 'If human rights exist, then they exist for other species too, so long as those species are capable of experiencing pains and pleasures.' One problem for the position of advocacy is that in a school classroom a teacher is almost always in a more powerful position than their students. There is therefore a risk than when a teacher adopts a model of advocacy in the teaching of a controversial issues, they may end up trampling on students' autonomy.

A second approach is one of *affirmative neutrality*, in which the teacher presents to their students as many sides of a controversy as possible, without indicating which they themselves support. This approach is more balanced than the approach of advocacy, though the teacher may find it difficult to avoid indicating their own views, especially if pushed by students. An additional problem is that the lesson may end up being somewhat dry and fail to engage the interest and involvement of many in a class.

A third approach is one of *procedural neutrality*, where the teacher acts as a facilitator. Information about the controversy and different points of view are elicited from students and source material. The teacher does not reveal their own position. This approach has a number of advantages but the collation of suitable source material may require a considerable investment of time by the teacher unless the developers of a course provide curriculum materials for students. Without suitable source material this approach runs the risk of failing to elicit a sufficient range of views from the students, in which case the lesson may become unbalanced or require the teacher to intervene in a manner more appropriate to the approach of affirmative neutrality or even advocacy.

Not all science educators have been convinced that these three approaches are appropriate. Oulton, Dillon and Grace (2004) argue that teachers have to make judgements about what information to present, and such judgements about controversial issues are necessarily subjective: “Even if the teacher thinks that they have presented matters as fairly as possible, others with different worldviews may still judge the presentation to be biased” (p. 416). They therefore argue that:

> An alternative, and to our knowledge as yet untested, approach, based on the reality of controversy, is to be open about the fact that balance can never be fully achieved but counter this by developing in pupils a critical awareness of bias and make this one of the central learning objectives of the work.
>
> (pp. 416-417)

The importance of a good understanding of the nature of scientific knowledge

There is a risk that some school students may think, when writing about or discussing a controversial issue, that any point of view is acceptable. This is not the case. Learners need to have a good grounding in the relevant science. Consider, for example, the issue of whether countries should invest in nuclear power. Here are some of the things one would want students (depending on their age) to know:

- Nuclear power relies on energy released from reactions that occur within the nuclei of atoms – unlike chemical reactions that occur between atoms and molecules.
- In principle, nuclear power can be obtained from nuclear fission, nuclear decay, or nuclear fusion. Nuclear fusion is still at the research stage. Nuclear decay, in which an unstable nucleus release energy while releasing alpha particles, beta particles or gamma radiation, produces only relatively small amounts of energy but has some niche uses (it is used in a type of nuclear battery that has no moving parts yet

generates electricity). Conventional nuclear power plants use nuclear fission, in which a nucleus spits into two or more smaller nuclei.

- In 2019, nuclear power produced about 10% of global electricity generation (International Energy Agency, 2019). However, this percentage is falling as ageing plants are beginning to close more quickly than new ones are coming on stream. Rare but heavily publicized accidents – such as those at Chernobyl in the Ukraine in 1986 and at Fukushima in Japan in 2011 – have contributed to a political climate in which nuclear power is viewed with more suspicion than was once the case.

Although the above list of bullet points is intended to be factual, some readers (and students in schools) might feel it is beginning to stray from science into more value-laded areas. Consider the sentence in the third bullet point: “Rare but heavily publicized accidents – such as those at Chernobyl in the Ukraine in 1986 and at Fukushima in Japan in 2011 – have contributed to a political climate in which nuclear power is viewed with more suspicion than was once the case.” Who decided what is ‘rare’? Does the phrase ‘heavily publicized’ somehow imply that nuclear power generation is subject to greater adverse scrutiny than other forms of power generation? How robust is the evidence that ‘nuclear power is viewed with more suspicion than was once the case’ and is this a scientific statement? Of course, these are precisely the sorts of issues a teacher might want students to consider. Such teaching would not only help students the better to understand the topic of nuclear power but might also give students a better understanding of some of the issues that fall within the Nature of Science (Kötter & Hammann, 2017).

Other pieces of knowledge could have been presented in the above list that would have been even more contentious. Advocates of the benefits of nuclear power often point to the fact that, notwithstanding rare Chernobyl or Three Mile Island (1979, USA) accidents, nuclear power generation is safer than other methods of generating electricity (e.g., Markandya & Wilkinson, 2007), also makes far less of a contribution to global climate change and allows electricity to be generated even when there is no wind and it is dark (unlike renewable power generation that relies on wind or solar power). Those who are less persuaded of the benefits of nuclear power point to the difficulties of dealing with nuclear waste, to the huge financial and human costs when there are occasional accidents and to developments in battery technology which mean that we may be able before long much more effectively to store the fruits of wind and solar power generation for subsequent use when generation is not possible or demand increases (e.g. Ylönen et al., 2017).

Again, this points to the difficulty of establishing precisely what are ‘the facts’. It is good for students to appreciate that there can be important scientific controversy that is not reducible to issues of values or ethics but is to do with scientific uncertainty. A final point is the value of students coming to realize that scientific knowledge varies in its robustness. It is possible that we will find other types of nuclear power in addition to nuclear fission, nuclear decay, or nuclear fusion but this is very unlikely. Our existing knowledge is robust. However, despite on-going advances in battery technology (e.g., Ma, 2021), our knowledge of their ability efficiently to store extremely large amounts of chemical energy is much less robust. This is science and technology being undertaken at the cutting edge.

The value of student research and argumentation

Controversial topics can be taught in a number of ways and can allow students to undertake research through reading relevant literature. There is a growing literature on the benefits of students undertaking independent practical research projects (Bennett et al., 2018; Rushton et al., 2021) and quite a lot is known about how school science textbooks and other materials can be made more readable (Sutton, 1992; Wellington & Osborne, 2001; Susetyadi, Permanasari & Riandi, 2020). In addition, a number of studies have been undertaken on the possible benefits for school students of reading literature (whether in books, on the internet or elsewhere) so as to inform their scientific views.

Britt et al. (2014) define scientific literacy “as the ability of people to understand and critically evaluate scientific content in order to achieve their goals” (p. 105). Their definition goes beyond merely listing scientific concepts, principles or vocabulary to be learned, being more in line with calls to focus on the skills and knowledge required to read and use scientific texts rather than simply understanding the main point of a text. Ritchie et al. (2010) showed that getting students to write could enhance student understanding of the issues relevant to their writing, and Ristanto et al. (2017) showed that guided inquiry instruction was more effective than conventional approaches at enhancing students’ scientific literacy.

There is a large research base on the value of student argumentation for their learning of science. Erduran and Jiménez-Aleixandre (2007) begin by pointing out the growing realization of the importance of discourse in knowledge production. Allied to this is a socio-cultural perspective “which points to the role of social interaction in learning and thinking processes, and purports that higher thinking processes originate from socially mediated activities, particularly through the mediation of language” (p. 4). Argumentation is particularly suited to controversial topics. Controversial topics are ones where different people hold different views, so there is benefit to students being able to articulate their own views and listen to those of others. In such articulation and listening, students can deepen their own views and improve the quality of their arguments by enhancing both their knowledge of the relevant science and the validity of their reasoning.

Another reason why argumentation is especially appropriate to leaning about controversial topics is that practical work often plays a smaller part in learning about such topics (Ping, Halam & Osman, 2020). Typically, what is a matter of contention cannot be resolved through practical activities that rely on the facilities and timescale available in a school classroom or laboratory. Rather, what is needed is the collation of relevant information, listening to others, and the use of discussion to develop a considered position.

This leads on to the value of including ethical thinking in school science. There are many controversial topics where ethics plays a role, particularly in biology (stem cells, genetically modified organisms, and cloning, for example), but also in other scientific disciplines (green chemistry, and sustainable electricity production, for example). Too often in school science teaching, little consideration is given to the quality of ethical reasoning (Chen & So, 2017). One can be most confident about the validity and worth of an ethical conclusion if three criteria are met (Reiss, 2010). First, if the arguments that lead to the particular conclusion are convincingly supported by reason. Secondly, if the arguments are conducted within a well-established ethical framework. Thirdly, if a reasonable degree of consensus exists about the validity of the conclusions, arising from a process of genuine debate.

Might some controversial issues be better thought of as sensitive issues?

Despite the adoption in this chapter of a broad understanding as to what is meant by a controversial topic, so that the epistemic criterion does not trump all other considerations, much writing and teaching in science education about controversy focuses on issues to do with epistemology. There is much of value in this. After all, we want students to search for scientific truth and to appreciate when it can be found and when claims to have found it are premature.

And yet, too great an emphasis on epistemology can be unhelpful in the classroom and can even lead to shouting matches between students, and a refusal to hear the points of views of others – precisely the opposite of what is wanted. It has been suggested that some controversial issues – particularly ones where individuals are heavily personally invested in them – might better be thought of as sensitive issues, on the grounds that:

> as humans most of us are quite good at knowing how to behave when dealing with someone for whom an issue is sensitive (think a bereaved friend or colleague, or someone worried about their sexual identity or whether their country should go to war): we are careful with our language, more hesitant in our speech, more alert to the possibility that the other person may be upset by something we say or some feature of our non-verbal communication.
>
> (Reiss, 2019, p. 357)

This approach shifts the emphasis from epistemology to pedagogy. One strength of this approach is that many teachers are good at dealing with sensitive issues, naturally respecting the feelings of students, even if they do not always agree with them (Lowe, 2015).

Examples of teaching controversial issues in science education

In this part of the chapter, three particular topics and examined to consider how they might be taught in school science. The precise content and approach will vary depending on the age and other characteristics of the students concerned; nevertheless, there are some general considerations that apply.

Evolution

In a number of countries, evolution has long been seen as the exemplar instance of a controversial topic in school science, not in terms of controversy over the basic science but more in terms of the depth of feelings it arouses and the very different positions about it that people occupy (Hermann, 2008). Most biologists see evolution not only as central to their discipline but as the core on which the rest of biological knowledge ultimately hangs. There are countries in which evolution is not included within the school curriculum for reasons of religion, and the topic is rarely included within elementary schools. Nevertheless, the importance of evolution for biology means that it is well represented in high school biology courses, even though it is cognitively demanding (Harms & Reiss, 2019).

The scientific understanding of biodiversity is far from complete and very little is known with any great confidence about the early history of life on Earth (Maynard Smith & Szathmary, 2000). How did the earliest self-replicating molecules arise? What caused membranes to exist? How key were the earliest physical conditions – temperature, the presence of water and so on? The scientific presumption is either that these questions will be answered by science or that they will remain unknown.

Whereas there is only one mainstream scientific understanding of biodiversity, there are a considerable number of religious ones (Pew Research Center, 2014). Many religious believers are perfectly comfortable with the scientific understanding, whether or not God is presumed to have intervened or acted providentially at certain key points (e.g., the origin of life or the evolution of humans). But many other religious believers adopt a more creationist perspective or that of intelligent design and it is this that makes evolution a controversial topic.

Many teachers of school biology are unsure how, if at all, to respond to creationism and intelligent design in the classroom (Deniz & Borgerding, 2018; Branch, Reid & Plutzer, 2021). If questions about the validity of evolution or issues about creationism and intelligent design arise during science lessons, they can often be used to illustrate a number of aspects of the Nature of Science, such as how interpretation of data provides evidence to test ideas and develop theories, that there are some questions that science cannot currently answer, and some that science cannot address, and that scientific ideas change over time.

In a mixed-methods study that used surveys and interviews to explore the views of Christian high school teachers in California and Hawaii, Mangahas (2017) found that teachers' beliefs regarding evolution and their Christian faith were varied and complex. While the surveys showed that the stronger the teachers' religious beliefs, the more negative they were about the theory of evolution, the interviews revealed a nuanced set of classroom practices, with a number of teachers saying that their beliefs "caused them to model respectful disagreement while also pointing out any problem areas in evolutionary arguments" (p. 34). Generally, the teachers "were supportive of the teaching of evolution in Christian schools as it engaged students in critical thinking and better prepared them for college" (p. 35).

In a study in Israel of junior high school and high school biology teachers and of those responsible for developing classroom materials and training teachers, Siani and Yarden (2020) found a range of positions about the teaching of evolution, with some teachers opposed and some in favor. One Jewish religious former chief supervisor at the Ministry of Education stated: "Because, in all, this is a controversial subject ... I think it's done with a lot of sensitivity. Not with power. Gradually, teacher-training courses were opened and teachers could register, no one forced teachers to register. It was not done in a forceful way, so I did not get any complaints. I felt as an instructor that I had to stand by the teachers and give them tools so that they could face students who asked" (p. 439).

Climate change

Anthropogenic climate change (i.e., changes in the climate that result from human activities), can be considered a controversial topic but for reasons that are somewhat different from those that make evolution a controversial topic. While the scientific evidence for anthropogenic climate change has strengthened greatly over the last couple of decades, there is still more genuine controversy about the basic science than there is about the basic science of evolution. Furthermore, while there are connections between religiosity (a composite measure that takes into account not only religious beliefs but also practices – such as regular worship – and experiences – such as believing that God speaks to one) and non-acceptance of anthropogenic climate change, the relationship is complex (Carr et al., 2012).

Reiss, M. J. (2022) Learning to teach controversial topics. In: Handbook of Research on Science Teacher Education, Luft, J. A. & Jones, M. G. (Eds), Routledge, New York, pp. 403-413. DOI: 10.4324/9781003098478-36.

The topic of climate change can be a valuable one to teach in schools (Sharma, 2012). Among school students, the topic is rarely as personal as evolution is to some students and the fact that the science is more contested gives students more opportunities to adopt a range of positions. It is a multidisciplinary topic, even within science drawing on biology, chemistry, earth science and physics, and is conceptually perhaps less difficult for some students to understand. It can also be used to help student develop their digital technology skills (Bush et al., 2016). There is a literature developing on school students' understandings and alternative conceptions about climate change (Dawson, 2015).

A recent systematic review concluded that didactic, top-down approaches to climate change education have predominated and have generally been ineffectual in affecting students' attitudes and behavior (Rousell & Cutter-Mackenzie-Knowles, 2020). More positively, though, the review identified:

> participatory approaches which empower communities of learners to design their own climate change projects and modes of engagement with the issue … A small number of studies also focused specifically on affective approaches which provoke emotional and somatic responses to climate change issues and concerns through engagement with art, imagery and narrative … digital technology has also emerged as an approach which has multiple applications for producing innovative and empowering forms of climate change education … lastly, a very small contingent of the literature is orientated towards child-framed approaches to climate change education, which draw on the unique perspectives and experiences of children and young people to inform new frameworks and methods for teaching and learning about climate change.
>
> (p. 202)

This suggests that if students are empowered by being given the opportunity to manage their own learning to a certain extent, they engage with the issue to a greater extent and derive more benefit from their learning. It seems likely that this conclusion is not restricted to climate change education.

Vaccines

Most school and popular accounts of vaccination start with Jenner's work and an account of his classic 1796 experiment on eight-year-old Edward Phipps. Graphs are presented showing dramatic decreases, thanks to vaccination, in the incidence of smallpox, with its eventual eradication, to this day the only human disease eradicated by immunization. Yet, controversies over vaccination have existed since vaccines were first introduced over two hundred years ago (Durbach, 2004). Despite this, vaccination is not normally thought of as a controversial topic in the way that evolution and anthropogenic climate change are. However, vaccination education may be improved by considering it thus.

Nineteenth century objections included the arguments that vaccination did not work, or was unsafe, and that its compulsory introduction (e.g., the 1853 Compulsory Vaccination Act in the UK) violated personal liberties. Today's objections to vaccination overlap with these and include the following: vaccines don't always work; vaccines are not totally safe; requiring, or even just incentivizing, someone to be vaccinated or to have their child(ren) vaccinated violates personal liberties; vaccines are often made in ways that are morally unacceptable; the scientists or companies that make vaccines can't be trusted; governments that advocate vaccination uptake can't be trusted; vaccines are unnatural; vaccines are part of a conspiracy to poison us, take over our minds or control us in some other way (Reiss, 2020). The role of science in addressing these objections is limited. For example, objectors who cite efficacy or safety concerns are not saying that a cost-benefit analysis on the grounds of efficacy or safety comes down against the use of vaccines – indeed, such cost-benefit analyses very strong support vaccine efficacy and safety. Rather objectors are saying that vaccines don't *always* work and aren't *totally* safe. One cannot argue against these objections on scientific grounds.

Consider the objection that vaccines are often made in ways that are morally unacceptable. Students would benefit from appreciating that what one means by 'morally acceptable' is itself controversial. For example, a number of widely used vaccines use cells lines derived from fetuses that were electively aborted decades ago. While for many people elective abortions (i.e., terminations rather than miscarriages) are, at least in certain circumstances, permissible, for many other people they are not, often on religious grounds. These differences of opinion – deeply held convictions – cannot be reconciled by any method of science. They simply lie beyond science, being situated in the domain of moral philosophy or values more generally.

Examination of the reasons why people are hesitant about vaccines or reject them reveals a range of overarching considerations to do with history and identity. Many groups whose members show low uptake of vaccines have had a history of poor treatment or even abuse by the medical and broader establishment. Careful interviewing has revealed deep suspicions about vaccines amongst many black populations who were historically discriminated against both directly and indirectly (Lockyer et al., 2020). More generally, people vary greatly in the extent to which they trust those in power. This way of conceptualizing vaccine hesitation or rejection has important implications for vaccine education. It entails treating learners, whatever their age, with respect, rather than dismissing their concerns.

These conclusion about vaccination education mesh with the conclusions about climate change education and evolution education. Together, they suggest how teaching about controversial science topics can lead to an education that is respectful of learners and effective in teaching about science.

References

Bennett, J., Dunlop, L., Knox, K. J., Reiss, M. J., & Torrance-Jenkins, R. (2018). Practical Independent Research Projects in science: A synthesis and evaluation of the evidence of impact on high school students. *International Journal of Science Education*, *40*, 1755–1773. https://doi.org/10.1080/09500693.2018.1511936

Branch, G., Reid, A. & Plutzer, E. Teaching evolution in U.S. public middle schools: results of the first national survey. *Evolution: Education and Outreach*, *14*, 8. https://doi.org/10.1186/s12052-021-00145-z

Bridges, D. (1986). Dealing with controversy in the curriculum: A philosophical perspective. In J. J. Wellington (Ed.), *Controversial issues in the curriculum* (pp. 19–38). Basil Blackwell.

Britt, M. A., Richter T., & Rouet, J.-F. (2014). Scientific literacy: The role of goal-directed reading and evaluation in understanding scientific information. *Educational Psychologist*, *49*(2), 104–122. https://doi.org/10.1080/00461520.2014.916217

Bush, D., Sieber, R., Seiler G., & Chandler, M. (2016). The teaching of anthropogenic climate change and earth science via technology-enabled inquiry education. *Journal of Geoscience Education*, *64*(3), 159–174. https://doi.org/10.5408/15-127

Carr, W. A., Patterson, M., Yung, L., & Spencer, D. (2012). The faithful skeptics: Evangelical religious beliefs and perceptions of climate change. *Journal for the Study of Religion, Nature and Culture*, *6*(3), 276–299. https://doi.org/10.1558/jsrnc.v6i3.276

Chen, Y., & So, W.M. (2017). An investigation of mainland china high school biology teachers' attitudes toward and ethical reasoning of three controversial bioethics issues. *Asia-Pacific Science Education*, *3*, 1. https://doi.org/10.1186/s41029-016-0012-6

Claire, H., & Holden, C. (Eds.). (2007). *The challenge of teaching controversial issues*. Trentham.

Dawson, V. (2015) Western Australian high school students' understandings about the socioscientific issue of climate change. *International Journal of Science Education*, *37*(7), 1024–1043. https://doi.org/10.1080/09500693.2015.1015181

Dearden, R. F. (1984). *Theory and practice in education.* Routledge & Kegan Paul.

Deniz, H., & Borgerding, L. A. (Eds.) (2018). *Evolution education around the globe*. Springer. https://doi.org/10.1007/978-3-319-90939-4

Durbach, N. (2004). *Bodily matters: The anti-vaccination movement in England, 1853–1907*. Duke University Press.

Erduran, S., & Jiménez-Aleixandre, M. P. (Eds.). (2007). *Argumentation in science education: Perspectives from classroom-based research*. Springer. https://doi.org/10.1007/978-1-4020-6670-2

Hand, M. (2008). What should we teach as controversial? A defense of the epistemic criterion. *Educational Theory*, *58*, 213–228. https://doi.org/10.1111/j.1741-5446.2008.00285.x

Harms, U., & Reiss, M. J. (Eds.). (2019). *Evolution education re-considered: Understanding what works*. Springer. https://doi.org/10.1007/978-3-030-14698-6

Hermann, R. S. (2008). Evolution as a controversial issue: A review of instructional approaches. *Science & Education*, *17*, 1011–1032. https://doi.org/10.1007/s10972-012-9328-6

Hess, D. E. (2009). *Controversy in the classroom: The democratic power of discussion.* Routledge.

International Energy Agency. (2019). *Nuclear power in a clean energy system*. International Energy Agency. https://www.iea.org/publications/nuclear

Kötter, M., & Hammann, M. (2017). Controversy as a blind spot in teaching Nature of Science. *Science & Education*, *26*, 451–482. https://doi.org/10.1007/s11191-017-9913-3

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. *International Journal of Science Education*, *28*, 1201–1224. https://doi.org/10.1080/09500690600560753

Lockyer, B., Islam, S., Rahman, A., Dickerson, J., Pickett, K., Sheldon, T., Wright, J., McEachan, R., & Sheard, L. (2020). Understanding Covid-19 misinformation and vaccine hesitancy in context: Findings from a qualitative study involving citizens in Bradford. *UKmedRxiv*, 2020.12.22.20248259. https://doi.org/10.1101/2020.12.22.20248259

Lowe, P. (2015). Lessening sensitivity: Student experiences of teaching and learning sensitive issues. *Teaching in Higher Education*, *20*(1), 119–129. https://doi.org/10.1080/13562517.2014.957272

McLaughlin, T. (2003). Teaching controversial issues in citizenship education. In A. Lockyer, B. Crick, & J. Annette (Eds.), *Education for democratic citizenship: Issues of theory and practice* (pp. 149–160). Routledge.

Ma, J. (Ed.). (2021). *Battery technologies: Materials and components*. Wiley.

Mangahas, A. M. E. (2017) Perceptions of high school biology teachers in Christian schools on relationships between religious beliefs and teaching evolution. *Journal of Research on Christian Education*, *26*(1), 24–43. https://doi.org/10.1080/10656219.2017.1282902

Markandya, A., & Wilkinson, P. (2007). Electricity generation and health. *The Lancet*, *370*(9591), 979–990. https://doi.org/10.1016/S0140-6736(07)61253-7

Maynard Smith, J., & Szathmary, E. (2000). *The origins of life: From the birth of life to the origin of language*. Oxford University Press.

Oulton, C., Dillon, J., & Grace, M. (2004). Reconceptualizing the teaching of controversial issues. *International Journal of Science Education*, *26*(4), 411–423. https://doi.org/10.1080/0950069032000072746

Pew Research Center. (2014). *Religious groups' views on evolution*. Pew Research Center. https://www.pewforum.org/2009/02/04/religious-groups-views-on-evolution/

Ping, I. L. L., Halam, L., & Osman, K. (2020). Explicit teaching of scientific argumentation as an approach in developing argumentation skills, science process skills and biology understanding. *Journal of Baltic Science Education*, *19*(2), 276–288. https://doi.org/10.33225/jbse/20.19.276

Reiss, M. J. (2010). Ethical thinking. In A. Jones, A. McKim, & M. Reiss (Eds.), *Ethics in the science and technology classroom: A new approach to teaching and learning* (pp. 7–17). Sense.

Reiss, M. J. (2011). How should creationism and intelligent design be dealt with in the classroom? *Journal of Philosophy of Education*, *45*, 399–415. https://doi.org/10.1111/j.1467-9752.2011.00790.x

Reiss, M. J. (2019). Evolution education: Treating evolution as a sensitive rather than a controversial issue. *Ethics and Education*, *14*(3), 351–366. https://doi.org/10.1080/17449642.2019.1617391

Reiss, M. J. (2020). Science education in the light of COVID-19: The contribution of History, Philosophy and Sociology of Science. *Science & Education*, *29*(4), 1079–1092. https://doi.org/10.1007/s11191-020-00143-5.

Ristanto, R. H., Zubaidah, S., Amin, M., & Rohman, F. (2017). Scientific literacy of students learned through guided inquiry. *International Journal of Research & Review*, *4*(5), 23–30.

Ritchie, S. M., Tomas, L., & Tones, M. (2011). Writing stories to enhance scientific literacy. *International Journal of Science Education,* 33(5), 685–707. https://doi.org/10.1080/09500691003728039

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*, 155–169. https://doi.org/10.1007/BF01405730

Rousell, D., & Cutter-Mackenzie-Knowles, A. (2020). A systematic review of climate change education: Giving children and young people a 'voice' and a 'hand' in redressing climate change. *Children's Geographies*, *18*(2), 191-208. https://doi.org/10.1080/14733285.2019.1614532

Rushton, E. A. C., Charters, L., & Reiss, M. J. (2021). The experiences of active participation in academic conferences for high school science students. *Research in Science & Technological Education*, *39*(1), 90–108. https://doi.org/10.1080/02635143.2019.1657395

Sharma, A. (2012). Global climate change: What has science education got to do with it? *Science & Education*, *21*, 33–53. https://doi.org/10.1007/s11191-011-9372-1

Siani, M., & Yarden, A. (2020) "Evolution? I don't believe in it". *Science & Education*, *29*, 411–441. https://doi.org/10.1007/s11191-020-00109-7

Susetyadi, A. D., Permanasari, A., & Riandi, R. (2020). The feasibility and readability test of stem-based integrated science teaching book model themed "blood as transportation system on our body". *Journal of Physics: Conference Series, Science and STEM Education*, *1521*, 042054. https://doi.org/10.1088/1742-6596/1521/4/042054

Sutton, C. (1992) Words, science and learning. Open University Press.

Wellington, J. (Ed.). (1986). *Controversial issues in the curriculum.* Basil Blackwell.

Wellington J., & Osborne, J. (2001). *Language and literacy in science education*. Open University Press.

Ylönen, M., Litmanen, T., Kojo, M., & Lindell, P. (2017). The (de)politicisation of nuclear power: The Finnish discussion after Fukushima. *Public Understanding of Science*, *26*(3), 260–274. https://doi.org/10.1177/0963662515613678

Yuliastini, I. B., Rahayu, S., Fajaroh, F., & Mansour, N. (2018) Effectiveness of POGIL with SSI context on vocational high school students' chemistry learning motivation. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 85–95. https://doi.org/10.15294/jpii.v7i1.9928

Zeidler, D. L., & Sadler, T. D. (2008) Social and ethical issues in science education: A prelude to action. *Science & Education*, *17*, 799–803. https://doi.org/10.1007/BF03173684