**Controversies in science: to teach or not to teach?**

**Abstract**

Controversies in science are an essential feature of scientific practice. They are defined here as current problems that are unresolved because there are no accepted procedures by which they can be resolved or there are differing assumptions that affect the interpretation of evidence. Although there has been much attention in science education literature to addressing socio-scientific and historical controversies in science, less has been paid to the teaching of contemporary scientific controversies. Using semi-structured qualitative interviews with 18 teachers at different career stages in England, we investigated teachers’ social representations of scientific controversies using discourse of the collective subject (DSC). We found a consistency in teachers’ responses. Whilst scientific controversies were seen as an essential feature of how science works, they were not viewed as essential in science education. In contrast, they were represented as a distraction and dealt with informally, outside the planned curriculum and in response to students’ questions. Subject knowledge was considered a barrier to teaching controversies in science. We argue that teaching about carefully selected scientific controversies has the potential to contribute to teachers’ and students’ understandings of science and the nature of science. There are perceived to be few opportunities for teachers to exercise this in the English context. We suggest how the collective subject discourses might be used to open up discussion about teaching controversies in professional learning situations. Materials to stimulate discussion of scientific controversies could be useful in future curriculum development in science, but these would need to address the barriers of subject knowledge, access to literature and conflict with assessment-related priorities and a perceived need to advocate for trust in science.

**Keywords**

Scientific controversies, nature of science, science teachers

**1. Introduction**

Despite its everyday use, ‘controversy’ has different – and controversial – meanings in relation to science (Dascal, 1998; Venturini, 2010, amongst others). In this study, we understand controversies in science (scientific controversies) to be a “publicly and persistently maintained dispute” (McMullin, 1987, p.51) between scientists. Controversies are an essential feature of scientific practice: they are live, or current, problems that are unresolved because there are no accepted procedures by which they can be resolved, or because there are differing conceptual or methodological assumptions that affect the interpretation of evidence (Dascal, 1998). They begin “when actors discover that they cannot ignore each other and…end when actors manage to work out a solid compromise to live together.” (Venturini, 2010, p.261). This positions scientific practice as a live dialogical and argumentative activity, involving people, with the resolution of controversies serving to create, elaborate and refine theories and stimulate new research (Harker, 2015).

Scientific controversies have educational value because they provide insights into science in-the-making because through the teaching of controversies it is possible to observe the non-neutral character of science. To understand scientific controversies requires a focus on the detail, for example scientific questions, methods, claims, evidence (and the strength of evidence) supporting these claims, and differing ways of interpreting this evidence. The genuinely unknown answer to a controversy allows for the activation of intellectual tension in the minds of those who engage with it - a key condition in educating about controversial issues (Yacek, 2018). It is important to consider the importance of teaching about controversies in school science because these have been identified by sociologists and philosophers (e.g. Latour, 1998; Dascal, 1998; Scerri, 2016) as an important feature of scientific research, and therefore a characteristic of the nature of science. Garcia-Carmona and Acevedo Diaz (2017) note that scientific controversy (amongst other features of the nature of science) has barely been addressed in previous research in science education, but is essential if the goal is to orient school science education towards teaching methods that are closer to authentic scientific activity. In this study, we aim to find out how in-service teachers understand, value and use controversies in science.

**2 Controversies in science and science education**

**2.1 Defining controversies in science: no mere disagreement**

Controversies can be distinguished from disagreement. McMullin (1987) identified two necessary conditions for a disagreement to be classified as a controversy: it must be continuing and it must be public. That is to say, there must be argument and counterargument on both sides, and this must be expressed in oral or written form so that others can arrive at their own position. Dascal has argued that these controversies are central to any account of the history of ideas in science, in which they represent the “natural state of science...the locus where critical activity - essential for science - is exercised” (Dascal, 1998, p. 153).

Controversies can be distinguished in terms of who they involve and what they relate to. In her analysis of the theory of relativity in the 1920’s Wazeck (2013) identified different types of controversy in relation to science: those *in* science, those *about* science and a third type of controversy that relates to disagreements about the *nature of science*. Controversies *in* science are controversies between scientists in which there is disagreement about a knowledge claim (Wazeck, 2013). In these epistemological controversies, scientists share a common understanding of the nature of a problem such that the controversy can be resolved in science, but there may be disagreement over the most promising questions, methods or criteria for resolving the controversy. Recent high-profile controversies in science have included whether or not neurogenesis occurs throughout human life (Lee and Thuret, 2018), whether or not neutrinos can travel faster than the speed of light (Cartwright, 2018), and the composition of group three in the periodic table (Ball, 2017; Scerri, 2012). Actors in these epistemic controversies tend to be predominantly scientists.

Controversies about the nature of science also involve disagreement between scientists, but are not limited to the scientific community; indeed, in this class of controversy the knowledge claims are disputed by people outside the scientific community, but draw on commitments about the nature of science (Wazseck, 2013), and in this sense are ontological as well as epistemological. The example provided by Wazseck is the controversy about the theory of relativity, in which Einstein’s ideas were opposed by those who “shared an understanding of science as something clear and understandable and targeted at ‘truth’, to which modern physics formed the counterpart” (p. 184). That is, the theory of relativity was seen as controversial because it was perceived to change the relationship between science, truth and reality.

In contrast, controversies *about* science relate to ethical, political, economic, and social concerns, i.e. to a fundamental disagreement about the nature of a problem, in which scientists may be actors, but other actors in the controversy might include politicians, activists, and others. Although these controversies are constrained by science, they are not resolved using scientific methods. Such controversies tend to persist for longer than controversies *in* science (Wazeck, 2013). Much science education literature focuses on controversial issues about science (see for example Oulton, Dillon and Grace, 2007), i.e. socio-scientific controversies. Although these are often informed by scientific evidence, the dispute is more often a consequence of political and ethical positions (Ziman, 1994). It is also important to articulate the controversy precisely. A line of inquiry might produce controversies *about* science, controversies *in* science and controversies *about the nature of science*.

Whilst controversies *about* science and *about the nature of science*– and their treatment in the classroom - are important, they are not the type of controversy we focus on here; rather we focus on controversies *in* science. This is not to suggest that we believe these to be more important for appreciating the nature of science, nor to suggest that teachers should focus on one type of controversy. Rather, whilst the teaching of controversies *about* science is relatively well studied (cf. Kolstø, 2001; Levinson, 2006), controversies *in* science (i.e. epistemic disagreements between scientists which persist over time) are less well understood in educational settings.

**2.2 Scientific controversies in science education**

Given the arguments from philosophy and sociology of science that controversies are central to the nature or practice of science, it is perhaps surprising that there is little direct reference to controversies in textbooks (Niaz and Rodriguez, 2005) or curriculum documents. In England, for example, there is no explicit mention of scientific or other controversies in the curriculum. It is stated that students aged 11-14 should “understand that science is about working objectively, modifying explanations to take account of new evidence and ideas and subjecting results to peer review” (Department for Education, 2013, p.3), and that 14-16 year olds should understand “that science progresses through a cycle of hypothesis, practical experimentation, observation, theory development and review…teachers should feel free to choose examples that serve a variety of purposes, from showing how scientific ideas have developed historically to reflecting modern developments in science”. This suggests an incremental, constructive approach to how scientific knowledge is created, which favours an emphasis on the change of ideas over time, rather than on the mechanisms for this change. Whilst they do not explicitly exclude controversies in the classroom, nor do they acknowledge their existence or importance in the practice of science.

**2.3 The contribution of scientific controversies to ‘authentic’ school science**

In order for school science to become more authentic, there are calls for “inquiry that properly reflects that practiced by members of scientific communities” (Hume and Coll, 2010) so that students experience the type of knowledge – procedural and conceptual – needed to do scientific research. As we have argued above, understanding and/or participating in scientific controversy is one such practice. This is because it requires an understanding of, for example, theories that offer competing interpretations of evidence, an understanding of the evidence itself, and of the methods by which evidence is obtained - their capabilities and limitations. Whilst it is unlikely – though not impossible - that students would participate in a scientific controversy during their schooling, they certainly could be taught that scientific controversies exist, and use their scientific knowledge to understand the arguments in relation to different positions on the controversy. In the case of chemistry, the controversy about the composition of group three of the periodic table can be understood using high school chemistry (electron configuration and periodicity in physical and chemical properties). Understanding scientific controversies also implies an understanding of scientific concepts and theories, including those associated with experimental design. Through this type of exercise, students can gain insight into what it means to be a scientist, which has the potential to help them make more informed decisions about whether or not to pursue science further. Indeed, Latour (1987) has argued that what is important is the study of the settlement of scientific controversies rather than the products of scientific inquiries as the latter is the cause of the former.

Exclusion of controversies can result in teaching ‘final form’ (Duschl, 1990) or ‘readymade’ (Latour, 1987, p.4) science, rather than as science in-the-making. ‘Final form’ science not only risks excluding the “dialogic knowledge-building processes that are at the core of science” (Duschl, 2008, p. 269) that emphasise that science is a human endeavour from science classrooms, but also squeezes out opportunities for consideration of evidence, interpretation, identification of uncertainty and identification and discussion of questions central to the advancement of knowledge in science. It also presents a narrative of science that Meyer (2009) has described in terms of a distinction between ‘cold’ science, associated with certainty and ‘hot’ research, associated with uncertainty, and possibly contributes to the disconnect between ‘interesting’ science presented in the media and ‘school science’ observed by Osborne and Collins (2000).

The connection between school science and ‘hot’ scientific research has been explored by researchers interested in ‘authentic’ school science, such as Roth (1995) who argued that to have an authentic experience of science, students need to access enquiry experiences that have features in common with scientists’ activities. These ‘authentic’ science practices have been characterized by Edelson (1997) as including attitudes (of uncertainty and commitment), tools and techniques, and social interaction (including co-operation and competition). Returning to Dascal’s definition of controversy, we can consider controversies to be an authentic feature of scientific practice. Whilst high school students can – and do – contribute to the creation and resolution of controversies in science,[[1]](#footnote-1) recognising the existence of scientific controversies in teaching has the potential to enhance students’ understanding of science-in-the-making and to make explicit the social processes that lead to scientific knowledge so often hidden.

Inclusion of scientific controversies does not mean to say that scientific knowledge should be neglected. The very act of disagreement in a controversy provides an access point to understand where ties are being negotiated, which requires knowledge of the claims being made, and the basis and interpretations of these. Venturini, (2010) has argued that these are best observed when they are over-heating: in the present; not the past, and that these require an understanding of the best knowledge to date. Yanek (2018) has argued that in pedagogical situations, there is a need to pay attention to the psychological condition in the teaching of controversies, recommending directive teaching in order to activate intellectual tension in learners such that they understand the controversy.

An understanding of controversies in science therefore has the potential to engage learners with ideas about the nature and practice of science. However, controversies are by nature complex, and there is a tension between being able to observe or understand controversies in their unreduced complexity and the need to make them comprehensible for a wider public (Venturini et al., 2015), including students in schools. In this study we seek to understand if and how teachers represent scientific controversies, and their underlying beliefs and values in relation to scientific controversies.

**2.4 Research on teaching controversies in science**

There is a challenge in identifying scientific controversies appropriate for teaching because these are often inaccessible to the layperson, being played out at conferences, in the review of journal articles and in private communications (Harker, 2015), and also because they relate to contemporary science that has not yet made it into the curriculum.

Work on models of teaching controversies about science has been useful in categorising controversies in terms of their content. Levinson (2006) has argued that there is a lack of clarity about the epistemological and ethical structure of controversy, particularly in relation to citizenship and socioscientific issues (controversies about science). He used McLaughlin’s (2003) categories of reasonable disagreement to define and classify controversies in relation to socio-scientific issues (Levinson, 2006, p. 1208) and to outline an epistemological model of controversy consisting of categories of reasonable disagreement, communicative virtues and modes of thought. In this study, we are interested in controversies in categories 1 (where there is insufficient evidence available to settle a matter, but where such evidence could be forthcoming at some point) and 2 (where evidence relevant to settling the matter is conflicting, complex and difficult to assess). Sadler (2007) suggested selecting controversies where there are clear lines of data supporting different positions, and to focus clearly on highlighting how data may be interpreted differently, rather than socio-scientific controversies where ethics play a greater role (and may be used for different ends, such as teaching about the interaction between science and society).

Research on teaching scientific controversies includes proposals for teaching controversies in school science. These often focus on historical controversies in science, for example carefully planning questions that focus on the interpretation of empirical data from different theoretical perspectives in the context of reconstructing historical controversies in physics (Niaz and Rodriguez, 2002), or chemistry (Garcia-Carmona and Acevedo-Diaz, 2017). Some proposals have related to more contemporary controversies, e.g. considering data, interpretation and inferences in relation to controversies in order that students understand how scientists use data to make inferences in support of different positions (Sadler, 2007). Findings from these studies suggest that a focus on controversies can have an impact on learners; for example Garcia-Carmona and Acevedo-Diaz (2017) found a positive impact on beginning teachers’ conceptions of the nature of science through the use of the context of Pasteur and Leibig’s disagreement over the causes of fermentation. Some studies have involved creation of ‘contrived’ controversies, where situations are treated as controversies although the proponents were working at different times. For example, de Hosson and Kaminski (2007) have created a rational reconstruction from the history of vision, but their purpose is not to teach controversy but rather to deal with common student misconceptions similar to historical ideas. Presented in this way, the controversy is inauthentic, although potentially useful for promoting conceptual change. However, care must be taken with reconstructions as they may promote a whig view of history, in which the past is judged in terms of the present, “looking back with hindsight about what is known to be important later” (Henry, 2002, p.3).

Outside formal education, mapping of contemporary controversies has been used to engage the public with controversies in and about science, for example in relation to genetically modified (GM) organisms and food (Yaneva et al., 2009), where visitors examined the controversy using inquiry-based interfaces and an ‘unfinished’ cartographical approach to mapping controversies in a gallery space. Whilst this has resource (including space) implications beyond many school budgets, the focus on the actors, networks and disagreements in science has the potential to engage students in authentic dialogue in relation to science.

Although there has been much attention in science education literature to addressing socio-scientific controversial issues (Oulton, Dillon and Grace, 2004; Levinson, 2006) and historical controversies in science (De Hosson and Kaminski, 2007; Braga, Guerra and Reis, 2010; Garcia-Carmona and Acevedo-Diaz, 2017), less attention has been paid to contemporary scientific controversies. In this study, we aim to find out what teachers mean by scientific controversy and how this relates to their beliefs, practices and values associated with teaching scientific controversies.

**2.5. Social representations and science education**

The approach taken in this article to analyse teachers’ beliefs in relation to teaching controversies in science - discourse of the collective subject - has its basis in social representations theory (Moscovici, 1976), who defined a social representation as a system of values, ideas and practices which:

…establish an order which will enable individuals to orientate themselves in their material and social world and to master it...and enable communication to take place among the members of a community by providing them with a code for social exchange...and for naming and classifying unambiguously the various aspects of their world. (p xiii)

Social representations therefore include the beliefs, values and practices that are shared by teachers, which allow them to orient their practice and communicate with other teachers and act as a guide for communication and thinking about the social object. Here, social representations allow us to understand teachers’ common sense knowledge about teaching controversies *in* science.

Approaches based on social representations theory have been used in science communication and public understanding of science to understand how the media engages the public with climate change (Hoijer, 2011; Jaspal and Nerlich, 2014) and how the public represents climate change (Smith and Joffe, 2012), as well as in maths education (Martinez-Sierra et al., 2016), but are less often used in science education. Social representations, whilst not always consensual, provide a common code of communication even where practices can be fragmented and contradictory (Martinez-Sierra et al., 2016). A key way in which social representations theory can contribute to science education research is to illuminate the ideas and beliefs which underpin classroom practice and create a sense of group identity amongst teachers. We believe that it is possible, through the technique of collective subject discourse, to capture teachers’ social representations of scientific controversies and of the teaching of scientific controversies. In this article, we demonstrate this in action.

The aim of this research is to identify the social representations (i.e. the systems of behaviours, values, practices and attitudes) of secondary school science teachers regarding scientific controversies, and to find out to what extent and in what ways science teachers deal with scientific controversy with students. A social representation is a collective phenomenon, co-constructed by individuals (such as teachers) in their everyday talk and actions, which allows the group to develop its own interpretation of the unfamiliar (Wagner et al., 2007). The research question driving this work is ‘what are teachers’ social representations of scientific controversies and the teaching of scientific controversies?

**3 Method**

The aforementioned aims led us to the choice of qualitative, semi-structured interviews as a research method. Given that we were interested in representing knowledge used by teachers in their everyday interactions, we drew on a methodological approach that brings to light the social representations (in the sense defined by Moscovici and Duveen, 2000) of the interviewees, namely Discourse of the Collective Subject (DCS; Lefevre and Lefevre, 2007; 2014). This approach sees social representations not as linked to interpretive theories but as practical entities (Lefevre and Lefevre, 2007; 2014) and was developed in public health research in order to empirically present a collective opinion. To our knowledge, this has not been used so far in science education. This approach allowed us to focus on how knowledge is socialised into everyday common sense and teaching practice, and to create a series of texts, representing social representations, which have educational value in discussing how to teach controversies, and indeed science more broadly. DCS was selected because it reveals collective thoughts as social representations, which can be used to both understand collective practice and to shape future educational practice through reflection and interaction with the discourses.

**3.1 Participants**

We interviewed a total of 18 secondary teachers, 9 male and 9 female. They had all worked in the UK, having between 1 and 18 years of experience, and all were known to the researchers through professional networks including involvement in initial teacher education, curriculum development, and other research projects. Several participants had experience teaching in other countries and in other academic and industrial careers prior to entering teaching. Table 1 presents the background characteristics of the teachers in the study.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Sex | | Science specialism | | | Teaching experience  (number of years) | | | |
|  | Male | Female | Biology | Physics | Chemistry | <3 | Between 3 and 5 | Between 5 and 10 | 10 or more |
| number of teachers | 9 | 9 | 7 | 6 | 5 | 5 | 3 | 3 | 7 |

*Table 1: Characteristics of participants*

**3.2 Data collection**

To obtain teachers’ social representations, open interview questions were used to understand the ways that teachers represent realities, in this case, scientific controversies. Social representations have been studied using ethnographic approaches, focus groups, content analysis and questionnaires. We have carried out in-depth qualitative, semi-structured interviews, on a one-to-one basis with teachers, in order to help them explain their views and to describe their practices, beliefs and values in relation to science teaching, without feeling under pressure from peers to respond in a particular way, which may happen in group interview or focus group situations.

The research tool contained closed and open questions. The closed questions were used to gather personal information about the participants (age, name, sex, subject specialism, time in the profession and to outline any training or continuing professional development on teaching controversies they had experienced).

In the open section, we asked teachers what the meaning of controversy was to them, then of controversies in science more specifically. We included questions about what participants meant by and felt about teaching scientific controversies; if, how, and why they dealt with them in class; what place they saw for them; their own position on teaching controversies and how they related to their views of how scientific knowledge is created; and any challenges or difficulties they faced in teaching controversies. We also asked teachers to discuss the place of controversies in the creation of scientific knowledge. We chose not to focus on a specific controversy, but rather to allow teachers to talk about their own examples, because these are the controversies that teachers are working with, have experience of, and are most confident to discuss with students, and are therefore those which teachers are most likely to be able to talk about knowledgeably. Some examples were provided where these were not forthcoming from participants.

All interviews were transcribed, with participants invited to comment on their transcripts before they were analysed to produce discourses of the collective subject. These products (discourses of the collective subject) contrast with the presentation of interview or focus group data, which tend to be reported from an individual. Here, the discourses are collectively produced: individual interview transcripts are coded into semantic categories, and the social representation is reconstructed from key expressions from statements by individuals with similar meaning (Lefevre and Lefevre, 2007; 2014).

Although some studies using discourse of the collective subject report numbers, particularly when reconstructing discourses from questionnaire responses (Lefevre and Lefevre, 2007) this study is qualitative, in common with others (cf. Silva et al., 2010; Silva-Costa et al., 2010). A qualitative approach has been chosen because interviews are flexible and fluid, responding to the experiences of individuals, and as a result teachers do not discuss the exact same issues: of our 18 participants, having 9 people sharing a similar position does not necessarily mean that the other 9 held a different position; they may simply not have discussed the issue. Similarly, several teachers may express themselves in a broadly similar way. Furthermore, the value of the discourses is not determined by the number of people who held them, but by *what* they are.

The research was conducted in accordance with approvals gained from our appropriate institutional ethics committee, in line with BERA’s (2018) Ethical Guidelines for Educational Research, including the principles of voluntary informed consent, right to withdraw, privacy and minimisation of harm.

**3.3 Data analysis**

Following the transcription of the interviews, we imported the word files into NVivo. Discourse of the collective subject (DCS) reproduces social representations through a synthetic discourse, written in first person singular but made from the collective text. The social representations constructed are relatable and thus may be useful as a resource for later social intervention, for example in teacher education or continuing professional development situations (Lefevre and Lefevre, 2014). In discourse of the collective subject, the role of the researcher has been likened to that of an obstetrician, in which they help to deliver social representations as a construct or artifact made by reconstructing collective thought (Lefevre & Lefevre, 2014).

Social representations are created by anchoring and objectification. In anchoring, the unfamiliar - in this case, scientific controversies - are made familiar through the links that teachers make to other familiar ideas and practices. In objectification, abstract ideas are made concrete. Social representations become capable of influencing the behaviour of an individual (say a teacher) in a collectivity through professional activity - whether intended or not - and are a way of understanding and communicating shared knowledge (Moscovici and Duveen, 2000).

In line with that proposed by Vigeta et al. (2012), a four-step procedure was used to analyse the interview transcripts in order to create the discourses. First, we copied all responses to the same question for each respondent. We then highlighted key phrases that revealed the essence of each response, and subsequently identified the central ideas and key expressions (Table 2). This corresponds to anchoring processes, which is the expression of a given worldview by the research participants. In the example provided in Tables 2 and 3, the worldview is that ‘Scientific controversies are dichotomous and theory-dependent, and central to scientific practice’.

|  |  |  |
| --- | --- | --- |
| **Prompt: What do you understand by the term controversy in science?** | | |
| **Teacher** | **Key terms** | **Central ideas** |
| 1 | So, a controversy in science may be where there has been, for example, friction between two people within the scientific community or two groups within the scientific community. | Disagreement  Dichotomy |
| 2 | Okay, so the idea that there’s certain aspects to our knowledge in science that is either … well, there’s two levels. There’s between scientists there’s dispute about the veracity of, or the, you know, how accurate the research reflects reality and so whether or not it’s a valid theory and so on. And so you might have a controversy in science where there might be two groups that are arguing about different aspects of that part of science, or that part of research. And then there is the other kind of different level which is the public understanding of science and how it’s reported and, for example, global warming is considered a controversy in science outside of science, whereas inside science it’s pretty much wrapped up the theories that we have. There are elements where people are looking at different aspects of it, but the data collection and so on generally most people in the scientific community agree with that aspect, so there’s the lay person’s controversies that they hear about and then there’s scientific controversies within the community and so it’s basically a disagreement about the findings of a particular piece of research and so on. That’s how I understand it. It’s how we build our knowledge. | Actors: scientists  Disagreement  Theory  Dichotomy  Argument  Controversy *about* science  Theory  Methods  Disagreement  Scientific practice |
| 3 | It is where evidence for one scientific idea goes against evidence for a different scientific idea and they don’t agree | Evidence  Dichotomy  Disagreement |
| 4 | So, there is evidence to point to two separate theories, which would be mutually contradicting but because there is no evidence to disprove either of them at this point, you get arguments where people don’t have ground, I think this is more valid than this one, and so on. I think it is the level that kids interact with, because if I told kids right there are two theories on how the universe could work, this one is this, I don’t think they care all that much. They may be interested, but they will look at both pretty equally. | Evidence, Dichotomy  Falsifiability  Dichotomy  Theory |
| Etc. |  |  |

*Table 2: Anchoring. Example of extraction of key terms and identification of central ideas for first 4 teachers. This process was carried out for each teacher response.*

Finally, we created extracts corresponding to the discourse of the collective subject, in first person singular for each response (Table 3). These re-constructions - collective statements - consist of extracts of individual statements which represent a specified position in relation to themes. This objectification turns abstract ideas into a concrete object: a collective subject discourse. In doing so, we recognise that social representations have grown out of the discussions teachers have in making sense of controversies, as well as that although they act as a snapshot of representations, they are not static, but are modified in use and likely to change over time.

|  |  |
| --- | --- |
| **Key terms of the discourse** | **Discourse of the collective subject** |
| A controversy in science may be where there has been, for example, friction between two people within the scientific community or two groups within the scientific community. [T1]  There might be two groups that are arguing about different aspects of that part of science, or that part of research…and so it’s basically a disagreement about the findings of a particular piece of research. [T2]  It is where evidence for one scientific idea goes against evidence for a different scientific idea and they don’t agree. [T3]  So, there is evidence to point to two separate theories, which would be mutually contradicting but because there is no evidence to disprove either of them at this point, you get arguments where people don’t have ground. [T4]  Science is built on controversy. [T12]  It’s about how we build our knowledge. [T2]  It’s part of the evolution of science, and day-to-day science. [T18]  Every scientific idea is debated, and whenever something new is debated, it might just be debated when you submit something for peer review. [T12] | *A controversy in science may be where there has been, for example, friction between two people within the scientific community or two groups within the scientific community arguing about different aspects of that part of science. It’s basically a disagreement about the findings of a particular piece of research. So, there is evidence to point to two separate theories, but because there is no evidence to disprove either of them at this point, you get arguments where people don’t have common ground. Science is built on controversy. It’s about how we build our knowledge. It’s part of the evolution of science, and day-to-day science. Every scientific idea is debated, it might just be debated when you submit something for peer review.* |

*Table 3: Building the discourse of the collective subject for ‘Scientific controversies are dichotomous and theory-dependent, and central to scientific practice’.*

The collective subject discourse can be constructed from all participants, or just a subset. Each construction represents a worldview, or social representation, present amongst the participants that provide insights into the values, beliefs and attitudes that guide teachers’ practice.

**4. Results and Discussion**

From the analysis of interview transcripts, emerged six main ideas - social representations - of the subject we were investigating (Table 4). Although teachers focused on different examples, there was consistency in their responses in relation to the place of scientific controversies in science and science teaching. The teachers discussed three types of controversy: social/ethical, historical, and contemporary. We focus here on responses pertaining to scientific controversies (i.e. controversies *in* science), or where teachers perceived that scientific controversy existed – although teachers sometimes drew on examples of controversy that were both *in* and *about* science. Data was excluded where teachers were referring explicitly only to controversies *about* science.

|  |
| --- |
| **Teachers’ social representations of controversies in science teaching** |
| Scientific controversies are dichotomous and theory-dependent, and central to scientific practice.  Teaching scientific controversies is subordinate to teaching ‘the facts’ and  covering the curriculum  Teaching controversies is risky  In dealing with controversies, balance is achievable and desirable  Teachers must not share their own views  Teachers and students do not have sufficient knowledge to deal with scientific controversies in school. |

*Table 4: Teachers’ social representations of scientific controversy and the teaching of scientific controversy*

The discourses of the collective subject are presented in the following section, under the heading of the corresponding social representation.

**4.1 Scientific controversies are dichotomous and theory-dependent**

In the examples discussed, there was no discussion of controversial claims and rather a focus on ‘issues’ more broadly. The social representation of scientific controversy (as opposed to controversies *about* science) as involving two opposing positions and dependent upon theory was constructed as follows:

*A controversy in science may be where there has been, for example two groups within the scientific community arguing about different aspects of that part of science. It’s basically a disagreement about the findings of a particular piece of research. So, there is evidence to point to two separate theories, but because there is no evidence to disprove either of them at this point, you get arguments where people don’t have common ground. Science is built on controversy. It’s about how we build our knowledge. It’s part of the evolution of science, and day-to-day science. Every scientific idea is debated, it might just be debated when you submit something for peer review.*

In the discourse of the collective subject above, there is consistency with Dascal’s definition of controversy as a ‘live’ (i.e. current) problem that remains unresolved because there are no accepted procedures for resolution, and also with Harker’s (2015) discussion about where controversy can emerge, e.g. during peer review. For these teachers, controversies are central to the way science is done. There was also a recognition of the importance of the role of interpretation of data and evidence in controversies in common with Sadler (2007). This suggests that teachers see controversies in science as a feature of science, and understand how these are played out in public.

**4.2 Teaching controversies is subordinate to teaching ‘the facts’ and covering the curriculum**

Whilst teachers’ social representation was that controversies were central to scientific practice, they were not seen as central to science teaching - indeed, they were seen as distracting from the job of covering the curriculum. The collective discourse is as follows:

*The controversy is not the be all and end all. You want them to learn the facts, the science that they need for their GCSEs. Most teaching is heavily linked to assessment. We have to keep them on the curriculum. I would definitely say the idea of controversies in science takes a back seat to the science. What it maybe hides is that there was a controversy in the first place. I try to teach it in a way that it’s very much accepted. I think the use of controversy has got to be very carefully thought about and linked into the development of the idea rather than the fact that there was the controversy. I don’t think maybe the young people recognise that some things are controversial, they just take it as this is how it is, this is what I’m going to memorise for the exam. Often they won’t see any controversy or conflict so therefore we don’t have to deal with that and then put them back on what we need to focus on. They could get the top grades in the exams whether they could [deal with controversies] or not. I guess as scientists we are quite guilty of stating, ‘This is correct and this is not correct’ and actually there sometimes is room for more discussion.*

Where scientific controversies were addressed in class, this was often because they had been raised in informal discussions, or from students’ questions, rather than as a specific learning objective. For these teachers, the demands of the curriculum were prioritized, and as scientific controversies are not mentioned explicitly in either curriculum documents or exam specifications, there is a disincentive for teachers to use class time to focus on controversies. Controversies are therefore seen as a distraction from activities that are more directly perceived to support exam success.

The DCS shows that teachers see controversies as central to science, yet not central to science education. As discussed in section 1.3, controversies are a feature of authentic scientific practice. Their exclusion from science education misses the opportunity to engage students in how knowledge is created in the sciences, and as a result to generate interest in contemporary science and how it is done. It is further limiting in that students must have experience beyond learning ‘the facts’ – they need to *use* the facts, and to have the opportunity to make decisions when presented with disagreements, and where the answers are unknown. Whilst many scientific controversies require knowledge beyond the curriculum, some, such the examples we suggest in section 1.3, are accessible for high school students, and offer the possibility for students to learn curriculum content at the same time as dealing with unknowns, and learning about how science works. Introducing scientific controversies is in this way consistent with ‘teaching the facts’.

In spite of the discourse of reluctance to deal with controversies in science, teachers in the study talked about ways in which they could teach scientific controversy, for example through teacher instruction and questioning, concept cartoons, card sorts, problem-solving activities, discussion and debate, silent discussion, storytelling, using videos and news to introduce a controversy, ‘fact-checking’ activities, matching evidence to competing theories and teaching how to write extended arguments. This suggests that teachers can select appropriate pedagogies for dealing with scientific controversies.

The discourse around ‘teaching the facts’ conveys an image of science that is both singular and static, and of knowledge-creation in science as incremental and constructive. This is in common with other studies (Leden et al., 2015; Levinson and Turner, 2001) that have found that science teachers focus on teaching facts rather than the nature of science. This image of science is important because it is likely to shape how people interpret science beyond school. Teaching scientific controversies presents one way in which science can be presented as a live, or ongoing, dialogical and argumentative activity by offering a way in to understanding how scientific theories are created, elaborated and refined and through which new research is stimulated (Harker, 2015), and which require students to *use* the facts they have been taught. Controversies were considered by some teachers as something that “used to be like this, but now it is like that”, with some describing historical ideas as ‘ludicrous’ and outdated rather than as appropriate explanatory systems for their time. In this way, controversy loses its strength as a part of the process of making and doing science, and this is a missed opportunity to engage students with science as a live exciting intellectual and practical pursuit.

It is interesting that teachers’ representations of the role of scientific controversies in science contrasts so sharply with their representations of scientific controversies in science education, in common with a Swedish study of teachers’ views and practice in relation to Nature of Science (NOS). Leden et al. (2015) suggested that teachers need ways of talking about “authentic, complex and controversial topics” (p.1163), and argued that dealing with NOS requires competences that are important but unusual to develop in science (namely discussing, evaluating interpreting and reasoning) and that dealing with NOS risks excluding some students. The discourses produced here suggest that there is a need for ways of talking (and indeed thinking) about authentic, complex and controversial issues. Teaching controversies was also seen as exclusive in some senses, being reserved for students who brought the interest to teachers, or to students who were perceived to be ‘brighter’. Furthermore, the collective subject discourses presented here suggest that instrumental approaches to teaching may contribute to the disconnect, along with the inaccessibility of scientific controversies in a usable form (see section 3.6), and concerns that students have preconceptions about science and certainty that they do not want to overturn for fear it will undermine their confidence in science (see section 3.3). Until the curriculum and assessment system values students’ ability to handle uncertainty and controversy, it is unlikely to take a more prominent place in science classrooms. This ‘mismatch’ is worthy of further investigation.

**4.3 Teaching controversies is risky**

A third social representation that emerged was that teaching controversies in science is risky. The discourse was constructed as follows:

*I think if you focus too much on controversy the students come away with the idea that everyone’s arguing and so none of this is fixed, which isn’t a bad thing because that’s true, but it then means that they don’t trust it. It must be very confusing because you’re ‘we’re throwing out that theory now’ or ‘they can’t make their minds up’. You could overload them so they wouldn’t know what they were learning and you are accountable for teaching them so they can pass the exam. You have to think very carefully about how you explain it and how you teach it. You could be going against people’s viewpoints that they’ve been brought up with. That’s really tricky because they all come from different backgrounds and have had different experiences.*

Teachers considered it important that students trust science, and they were positioned themselves as advocates for science through their use of ‘we’ when discussing the scientific community. This corresponds to studies that have found that science teachers often feel obliged to advocate for science when considering controversial issues (Jones, 2007).

Part of this advocacy for these teachers involved representing science as more certain than other ways of knowing, and there was some concern that teaching controversies – and explicitly revealing disagreement within the scientific community – undermines students’ trust in science, particularly, although not exclusively, where the controversies were contrived or were a result of scientific fraud. This positions controversy as an unhelpful feature of science when it comes to students’ trust in science, and the perception that this is secondary to teaching scientific knowledge. This representation is problematic because it mis-represents science, and misses the opportunity to teach about disagreement and uncertainty (as opposed to human error) inherent in science, and how scientists try to know what is currently unknown. Disagreement – and how scientists use this to drive research – is a strength of science: “Being a scientist requires having faith in uncertainty, finding pleasure in mystery, and learning to cultivate doubt. There is no surer way to screw up an experiment than to be certain of its outcome.” (Firestein, 2012, p.??). There is therefore an obligation for science teachers to ensure that students know how scientists deal with disagreement and how it is used to drive further investigation. This ought to be reason to reinforce rather than undermine students’ trust in science.

The interviews revealed that teachers were concerned about how (mis)-understandings of certainty and uncertainty had played out in the context of climate change, and in the context of anti-expert rhetoric in society which they saw as undermining public trust in science. As a result, dealing with science in less-than-certain terms in relation to controversies in science was seen as risky. Yet it is by being upfront about this characteristic of how science works, that it is possible to engender trust. As Millstone and Van Zwaneberg (2000) argued, the public “do not want ‘sedation’; they want to be privy to what is known, what remains uncertain, and where we might remain ignorant. They want to know the extent to which scientists can and do disagree” (p.1308). Here, the role of using controversies in science in teaching has the potential to demonstrate how public disagreements in science are resolved, and how, for example, competing theories, claims, or interpretations are considered and resolved.

The final risk was associated with topics where there might be elements of controversy that extended beyond the purely scientific, for example where the scientific controversy had implications for individuals’ religious or political views, or their views about the nature of science, i.e. where controversies *in* science intersected with controversies *about* science or *about the nature of science*. Teachers did not want to be insensitive to individuals, and felt that care needed to be taken to protect individuals. They also felt that consideration should be given to what parents and other influential bodies such as schools, the church and the school inspectorate would think. This included, for example in the case of vaccinations, the distinction between what they saw as legitimate objections to vaccinations that individuals might have such as compromised immune systems or allergies and arguments made on the basis of Wakefield’s 1998 paper on autism which was later retracted and found to be fraudulent (Goodlee et al., 2011). It is important for teachers to distinguish between controversies that arise within the scientific community, and those that include social, ethical and economic disagreements (controversies *about* science) because the methods for resolving these different types of controversy are different. In the case of teaching about controversies *in* science, which is our focus here, students may come to learn for example, what reproducibility in science means and why it is important, the relationship between theory and observation and experimentation, and the importance of refutation in experimental design. Rather than undermining trust in science, this suggests some reasons that knowledge gained using scientific methods may be trusted.

**4.4 Balance is achievable and desirable**

The collective discourse around the position of the teacher focused on the concept of ‘balance’ and teachers seeing their role to present ‘both sides’. This was seen as both possible and desirable, and related to the social representation that teachers must not share their own views. It was also associated with the social representation that teaching controversies is subordinate to teaching ‘the facts.’ There was little discussion about the multidimensional nature of controversies. The discourse of the collective subject is as follows:

*I’ve got to be quite careful sometimes just in that sense in a classroom that I give a balanced argument. You need to present both viewpoints, to sort of really analyse both sides thoroughly and then put those ideas together and come up with a balanced conclusion. You know, you have got to try and be as unbiased or as unjudgemental as you can, obviously don’t try to influence their own opinions either way. Reading around our subject is really important because as teachers we’re there to allow them to find their own way. It’s having the ability to research and understand other points of view, talk about the different bits of evidence for and against, think about logically both sides, weigh up the arguments, look at data, to then take them on board and add them to their own skill base and then being able to make their own decisions and again form opinions. You can make decisions the other way and they are still valid from that point of view.*

Several teachers observed that students were unlikely to have strong emotional responses to controversies *in* science in the way that they would have in relation to controversies *about* science. However, as the collective subject discourse in relation to scientific controversies demonstrates, the pedagogical imperative was to present different positions and enable students to arrive at their own position. This corresponds to findings in the field of teaching socio-scientific issues. Oulton, Dillon and Grace (2004) were concerned that the requirement or perceived requirement to maintain balance is unhelpful as such balance is likely to be impossible (owing to the fact that teachers make decisions about inclusion and exclusion of materials and arguments). They thus called for teachers to develop a critical awareness of bias instead, sharing their own position such that students can interpret teaching in light of this. Whilst the teachers in this study knew what is needed in order to address scientific controversies, this is subordinate to what is seen as important in science teaching (see section 3.2).

In contrast to controversies *about* science, where balance is likely to be illusory, in the case of controversies *in* science, the pursuit of balance is perhaps more credible because teachers and students alike are less likely to be emotionally invested in competing positions: the disagreement relates to intellectual rather than emotional tension. Yanek discussed the importance of creating intellectual tension in learning, and science education research and practice (cf. Shayer, 1999) has highlighted the importance of cognitive conflict in bringing about learning. The teaching of controversies in science is one way of bringing about such conflict and encouraging students to consider what they need to know or understand next in order to resolve the conflict or tension, or in the case of historical controversies, what was done. This suggests a challenge for textbook authors and curriculum developers to create materials that present scientific controversies in a format suitable for use in teaching.

**4.5 Teachers must not share their own views**

Connected to maintaining balance was the collective discourse of the teacher as being objective:

*I try and just present to them the facts that two bodies of scientists had get the students to make their own decision, I try not to take sides. I think that might be wrong of me. I can provide a lot of influence so that is why I have to be careful what I am saying. It’s not my job to say, “This is right”, or, “This is wrong”; it’s to give the information and let them come to their own opinion having considered all the aspects. I think as a teacher you’ve got to be really like non-biased, because obviously as a teacher if you say you think that then they might be swayed to think the same even though they might not actually think the same, if you see what I mean?*

Examples of controversies (past and present) that teachers addressed included the cause of the extinction of dinosaurs, the use of string theory to unite quantum mechanics and general relativity, when does human biological life begin, gender assignment and reassignment in intersexuality, and the design, implementation and interpretation of various epidemiological studies. In addition to the scientific controversy, some of these issues raise other types of controversy *about* science and *about the nature of science*.

The discourse represents the idea that it is possible - and desirable - to present ‘all the information’ so that students might make up their own minds, rather than focusing on identifying where the gaps in knowledge were, or analyzing what the underpinning assumptions of different positions were. In demonstrating the types of questions that need to be asked and lines of inquiry that need to be followed in relation to a controversy in science, teachers can demonstrate how scientific controversies might be resolved – and the role of scientists within this. Henderson et al (2015) argued that “the undervaluing of critique within the curriculum and pedagogy of school science results in a failure to develop the analytical faculties which are the valued hallmark of the practicing scientist; a misrepresentation of the nature of science; and, more importantly, a less effective learning experience.” Consideration of scientific controversies in the classroom presents one way of valuing critique, but examples must be selected carefully in order to avoid conflict with teachers’ beliefs that were identified in section 3.3.

As in the teaching of controversies *about* science, there may be too much emphasis on having ‘the answer’ or ‘a decision’ neatly tied up at the end of the class, rather than on identifying new questions, uncertainties and controversies that present science as it actually is: a live, dialogical, open-ended human activity.

**4.6 Teachers and students do not have sufficient knowledge to deal with scientific controversies in school**

Knowledge was an important anchor in these discourses, both for the teachers and for students. Teachers discussed the limitations of their own subject knowledge, and none of the teachers we interviewed had experienced science-specific continuing professional development on teaching controversies. Several mentioned informal conversations with colleagues that informed their approach, particularly in response to controversial issues that arose in class.

*I think one of the big things is about teachers being informed about what are the controversies going on out there at the moment. I’m sure there are controversies going on right now but as teachers we don’t know about them. My own interests dictate what I have read or looked into myself, that limits the knowledge on other things. If there was something controversial I knew that was coming up, I wouldn’t know enough about to talk with any expert opinion on it. I’d have to familiarise myself with the content and the topic. I don’t want to give false information back to them so I will limit it based on how much my own knowledge is just making sure that I won’t go too far into a subject and try and avoid anything, if I am not certain.*

Teachers discussed the difficulty in finding out about contemporary scientific controversies and in translating what was going on in the science community to the classroom. This is perhaps unsurprising given that scientific controversies exist between scientists and are negotiated, for example, behind the paywalls of scientific journals. This suggests there is a need to consider how teachers can keep their subject knowledge up to date, particularly at the frontier of their subject where the controversies are to be found in science-in-the-making. The open science movement, which aims to make scientific research and data accessible for all, may resolve this issue of teachers’ access to information in due course. Similarly, scientific publications aimed at schoolteachers might highlight pedagogically appropriate controversies in science and draw out what the controversy tells us about how science works.

In addition to their own subject knowledge, a social representation that emerged was that students do not have sufficient subject knowledge to handle scientific controversies.

*It’s really difficult to teach the development of the science until you have enough understanding of the science I think. At the younger levels you almost don’t want to overcomplicate some of this so you almost teach a more simplistic version of the issues. You’ve got to remember that you're teaching students who have a certain amount of knowledge. I have a good understanding of the history and so on and there’s development of the ideas, but to teach that to students who have no understanding of the science is really difficult because the two intertwine. You have got to choose your point carefully, because at the same time you are trying to get them to learn something, and if you give them too much too early it will confuse them. if you go too abstract too soon, they are just going to get overloaded.*

This perception that extended subject knowledge must be taught in order to understand controversies is problematic in that it is not clear when one has sufficient knowledge to handle controversy. In fact, closer examination of controversies has the potential to ensure that students have accurate subject knowledge and are able to apply it. Subject knowledge is vital in understanding controversies – and in knowing where disagreement is. The example we provide in relation to the periodic table in section 1.1 is accessible using high school subject knowledge, as are examples from astronomy, epidemiology and public health. Teaching scientific controversy requires more than knowing: it calls for questioning, application, evaluation and argumentation in assessing different knowledge claims.

Teachers also responded that they might deal with controversies with older or ‘brighter’ students, reporting that students typically don’t have sufficient breadth and depth of knowledge to know e.g. which model is better at explaining phenomena. However, Bromme et al. (2008) found that gains in factual knowledge sometimes result in less sophisticated epistemological beliefs, so there may be times when depth is preferable to breadth of knowledge. When considering controversies for use in the classroom, it is therefore important to ensure they are accessible to teachers and students, and that they are aligned with curriculum content.

**5. Conclusions and implications**

The aim of this research was to identify the social representations: the systems of behaviours, values, practices and attitudes of secondary school science teachers regarding scientific controversies, and to find out to what extent and in what ways science teachers deal with scientific controversy with students - or not. This was a challenge as teachers had more experience in dealing with controversies *about* science than they did dealing with controversies *in* science. Few teachers in the English context have had much instruction in the nature of science or how science works, and none of the teachers in this study had any formal training in dealing with scientific controversies. Teachers were able to identify and locate examples of scientific controversies and discuss examples of appropriate pedagogies to teach about controversies *in* science. There were a number of barriers to teachers dealing with scientific controversies: subject knowledge, access to literature and potential conflict with their priorities in relation to examinations and assessment and their perceived need to advocate for trust in science.

Teachers’ social representations of scientific controversies in the teaching of science were that they are dichotomous and theory-dependent, and central to scientific practice, but teaching scientific controversies is subordinate to teaching ‘the facts’ and covering the curriculum. Whilst we see teaching scientific controversies as consistent with teaching ‘the facts,’ examples have to be carefully chosen such that they align well with the examined curriculum. There is also a need to review the existing assessed curriculum in England if ‘teaching the facts’ is excluding other important features of science education from classrooms.

Scientific controversies were seen to make a demand on teachers’ and students’ subject knowledge. Scientific controversies to be used in high school teaching must therefore be carefully selected to be accessible with high school subject knowledge. Scientific controversies were represented as risky because they present a challenge to students’ trust in science. On the contrary, we see controversies in science as a way of introducing how science works to students, through which they can come to understand features of science such as reproducibility, inquiry and refutation. Through a better understanding of what science is able to do, and to the limits of scientific certainty, students will be better prepared to assess purported claims in the media. Related to this, in dealing with controversies, teachers represented balance as both achievable and desirable with the representation that teachers must not share their own views. These issues are acute when dealing with controversies about science. In the case of controversies *in* science, there is unlikely to be strong emotional investment (from teachers or students) in the resolution of the controversy as the competing claims do not extend to the social, ethical and economic realm. In scientific controversies, resolution instead relies on identifying assumptions, and generating scientific questions and lines of enquiry, which have educational value, particularly in their contribution to ‘authentic’ science education.

These findings provide us with a deeper understanding of how these teachers perceive and teach scientific controversies – or not - and their reasons for so doing. Our results suggest that teachers’ social representations of science and scientific controversy contrast with their representations of science teaching. Controversies were represented as an important aspect of science, but a distraction in science education, where learning (examined) curriculum content was prioritised. Recently, the GCSE (General Certificate of Secondary Education) qualification was reformed to include “more challenging knowledge-based content” (Department for Education, 2016). Instrumental approaches to teaching as a result of high stakes accountability regimes may mean that scientific knowledge is assessed to the point of exclusion of important aspects of the nature of science from science classrooms. Other possible reasons for the disconnect are found in the discourses and relate to teachers’ subject knowledge, perceptions about students’ ability to deal with controversial issues and challenges to students’ beliefs about science.

Discourse of the collective subject allowed us to identify social representations based on the ideas and identities of teachers, in terms of what their priorities and pressures are. These provide a point of departure for discussing nature of science in science education beyond scientific controversy. The discourses of the collective subject provide a concrete product to initiate discussion amongst teachers at different career stages about the affordances – or otherwise - of teaching using scientific controversies, and how best to align this aspect of authentic science with teachers concerns about curriculum coverage and teachers’ and students’ scientific knowledge. They can also inform curriculum developers, providers of professional development and instructional designers about teachers’ beliefs, values and attitudes.

When considering the use of controversies in the classroom it is important to be clear about what the controversy is, where the disagreement is located and why. It is also important to explain how a controversy might be resolved in different ways depending on whether it is a scientific controversy or a controversy about science. When discussing scientific controversies, there may be value in moving from a focus on controversial issues to controversial claims. This would have the effect of both narrowing the scope in terms of scientific knowledge requirements, placing greater emphasis on the role of evidence, as well as emphasising the structure of arguments, where the controversy is played out, between whom and on what grounds the controversy is disputed. Attention to the resolution of scientific controversies brings to consideration the social context of production of scientific knowledge through conferences, peer review and publication in journals, which are important in understanding the sociology and politics of scientific knowledge creation. Recognising controversy as an important element of how science works and how scientific knowledge is created could also be an important step in shaping the way the general public understands and perceives science.

Attention to controversies by textbook writers and curriculum developers and examiners would allow a real-life focus on criteria that distinguish facts, theories and opinions in the context of science-in-the-making. However, scientific controversies need to be carefully selected such that the science required is at a level appropriate such that students are equipped to understand the controversy.

There is a need for greater support for teachers in handling scientific controversy, particularly within the constraints of the curriculum. This may be achieved through design-based research, carried out with teachers, and professional development to work with scientific controversies that link well with assessed content. This has the potential to make science education more authentic, with a greater focus on interpretation of evidence, identification of as-yet-unanswered questions, analysis of risk and decision making in complex contexts. This might include some key questions that help students and teachers alike to examine a contemporary controversy in science. For example, by asking how evidence could be interpreted using different theories, the strengths and limitations of different methodological and analytical tools, and what further evidence is needed to decide between competing explanatory systems and how this should be gathered. The current emphasis on research impact (social as well as academic) for practicing scientists may provide the conditions to encourage collaboration between scientists, science educators and curriculum developers.

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1. see for example the work of the Institute for Research in Schools <http://www.researchinschools.org/staff.html> and the Journal for Activist Science and Technology Education 2018, Volume 9, No. 1. <https://jps.library.utoronto.ca/index.php/jaste/issue/view/1990/showToc> [↑](#footnote-ref-1)