Enhancing the quality of argument in school science

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Argument is fundamental to scientific understanding and progress. How can we help young people to develop their ability to use it?

Why argument?

Contemporary science impinges directly upon many aspects of people's lives. Individuals and societies have to make personal and ethical decisions about a range of socio-scientific issues, such as genetic engineering, reproductive technologies and food safety, based on information available through the press and other media. Often accounts of new developments in science report contested claims. Evaluating such reports is not straightforward as it requires, for instance, the ability to assess whether the evidence is valid and reliable, to distinguish correlations from causes or hypotheses from observations (Millar and Osborne, 1998). Within the context of a society where scientific issues increasingly dominate the contemporary landscape (Beck, 1992; Giddens, 1999), there is an urgent need to improve the quality of young people's understanding of the nature of scientific 'argument'.

Consequently, an important task for science education is to develop children's ability to understand and practise valid ways of arguing in a scientific context. They need to be able to recognise not only the strengths but also the limitations of such arguments. In our work, then, we have sought to study whether the quality of young people's 'argument' about scientific issues, and their critical capabilities, can be enhanced in science lessons. For instance, can the abilities to reason, use and criticise argument within a scientific context be taught? And, perhaps more importantly, can these abilities be improved? This is what we are attempting to do in our project 'Enhancing the Quality of Argument in School Science' (EQuASS), funded by the Economic and Social Science Research Council.

First, it is important to point out that by 'argument' we do not mean the pejorative use of the word with its confrontational connotations. We mean the putting forward of reasons where **claims** are justified by relating them to the **data** on which they are based. Evidence for any claim consists of at least two components – **data** and **warrants**. Warrants are essentially the means by which the data are related to claims providing the justification for belief. Thus the claim that diversity of species is a product of random variation and selection by the environment was supported originally by Darwin's data on the variety of finches' beaks found in the Galapagos. The warrant was that each adaptation gave each species a competitive advantage that ensured their survival on a particular island. A simple representation of an argument is provided by Toulmin (1958) (Figure 1).

ABSTRACT
This article makes a case for why teaching about 'ideas and evidence' requires more attention to the teaching of argument in school science. Based on research work at Kings' College London conducted with local teachers, it outlines various practical methods and strategies by which this might be achieved. The difficulties and obstacles are also explored.

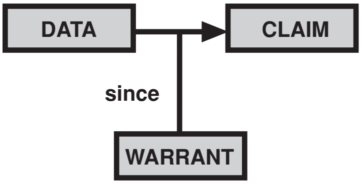


Figure 1 A simplified version of Toulmin's (1958) 'Framework for argumentation'.

It can easily be demonstrated that science education – as distinct from science – too often ignores the justification and arguments for scientific belief, and uses arguments from authority. Try asking any group of people the reasons for believing in the following fundamental tenets of school science:

- day and night are caused by a spinning Earth
- matter is made of atoms
- we live at the bottom of a sea of air
- diseases are caused by tiny living microbes
- all matter is made of only 92 elements

Few, if any, are able to provide the essential piece of evidence for the first (see end-note), let alone the evidence for the other statements. Such failings expose the weakness of a science education that has placed its emphasis on *what* should be believed rather than *why* it should be believed. Granted, arguments from authority are a legitimate form of argument. However, the lack of arguments that rely on warrants, other than those of authority in the science classroom, is a grave omission. The discipline of science is distinguished by its *central commitment to evidence* as the *basis of justified belief about material causes* and the rational means of resolving controversy (Siegel, 1989). Failure to emphasise this distinctive feature of science is, we would contend, ultimately self-defeating, leaving students with beliefs that they are unable to justify to others.

In the science classroom, argument often becomes a monologue – a one-way conversation where the pupils cannot engage in genuine questioning of the teacher because they lack the resources to challenge his or her assertions. As a result, the world is portrayed as a set of absolutes, characterised by 'right' and 'wrong' answers, with the origins of scientific ideas, the warrants and data for their belief, and any element of uncertainty simply excised.

The development of thinking

As well as the need to understand argument on contemporary science issues, there are good cognitive and social reasons for valuing argument in science education. From the cognitive perspective, constructing arguments is central to the process of thinking and is best developed through reasoning in public (Billig, 1996; Kuhn, 1992). Therefore, lessons involving argument should require pupils to engage in discussion and argument in small groups. Offering pupils the opportunity to engage in argument, opposing and supporting each other, promotes critical thought and develops their knowledge, beliefs and reasoning (Quinn, 1997). Monk and Poston (1999), in comparing science and music education, point out that, while the music curriculum provides opportunity for '*listening or appraising*', its equivalent in science – the critical consideration of '*the power, value and beauty of a scientific theory*' – is only given marginal significance in the science curriculum. Yet, is not thinking about science and being able to talk and criticise scientific argument an equally important skill to develop?

Approaching argument in the science classroom

How then can the process of argument in science be modelled and incorporated into activities for pupils? What problems will it cause for science teachers? Answering these questions was the fundamental aim of our research project. We have worked with a group of 13 teachers for the past year, attempting to develop materials to illustrate the process of argument and expose pupils to its use and crucial role in science. During the course of the year, the teachers have taught nine argument-based lessons. We have met with the teachers for five half-day sessions to share their experiences, improve resources and discuss and explore some of the underlying ideas. What, for instance, constitutes a good argument in science, and how is its quality to be measured? What are the most effective materials for initiating argument in school science, and how can the process of arguing be supported? What follows is an illustration of some of the materials that we have developed, a discussion of some of the strategies that support argument, and an illustration of the ways in which argument can be modelled for pupils.

Materials for argumentation

In approaching this work, we and the teachers have developed a set of 10 generic frameworks to support the process of argument in the science classroom. At the core of all of these materials is the presentation of more than one interpretation of evidence. The consideration of alternative interpretations of evidence demands comparison and contrast, forcing pupils and teachers alike to raise the questions: *'How do we know*

Example 1: Competing theories A

Theory 1: Light rays travel from our eyes to the objects and enable us to see them.

Theory 2: Light rays are produced by a source of light and reflect off objects into our eyes so we can see them.

Which of the following pieces of evidence supports Theory 1, Theory 2, both or neither. Discuss.

- **a** Light travels in straight lines.
- **b** We can still see at night when there is no sun.
- **c** Sunglasses are worn to protect our eyes.
- **d** If there is no light we cannot see a thing.
- **e** We 'stare at' people, 'look daggers' and 'catch people's eye'.
- **f** You have to look at something to see it.

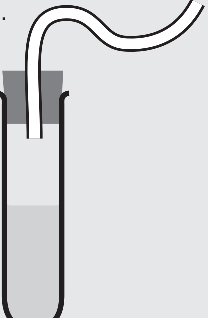
Example 2: Competing theories B

Theory 1: Microbes are made from rotting material. This is helped by flashes of lightning, bright light and warmth.

Theory 2: Microbes are carried in the air, probably on dust, and cannot be made out of dead matter.

Discuss whether the following pieces of evidence support Theory 1, Theory 2, both or neither.

- **a** Boiled soup in a sealed glass flask will keep forever.
- **b** If cartons of milk are opened, they will not stay fresh.
- **c** If the air was full of microbes, you wouldn't be able to see at all.
- **d** If milk is heated and sealed, it will keep for several days.
- **e** Boiling any material kills the vital ingredients needed to make microbes.
- **f** Boiled soup, exposed to the air with a special S bend tube in it like the one shown here, does not go off.
- **g** Food goes off more quickly in the summer when it is warm and humid.



... *?', 'What is the evidence for ... ?'* Since many of the phenomena focus on topics involving common misconceptions, they provide a natural means to consider and challenge pupils' ideas. Thus many of the more successful materials we have developed have taken the form of competing theories, as in Examples 1 and 2. These have been presented to pupils to read and discuss in small groups. Pupils are then asked to decide whether the evidence presented supports theory 1, theory 2, both or neither.

The third example requires the construction of an argument, relating pieces of evidence to the conclusion. This example also contains some statements which are data, including observations which are incontestable such as (b), and claims, such as (c), which are contestable for lack of data. This illustrates different kinds of 'evidence' used in scientific arguments. Considering evidence and its implications is the kind of activity that scientists are commonly engaged in. So pupils are asked to consider the statements and arrange them in a sequence with logical connectives that show a line of argument from the evidence to the statement. Again, this activity is done by pupils working in small groups discussing what they think is the most appropriate answer and why.

Example 3: Constructing an argument

Heavier things do not always fall faster

Look at the following statements of evidence. Discuss them with the others in your group and put them in a logical order to justify the statement above.

- **a** A penny and a brick reach the ground at the same time when dropped from the same height.
- **b** Air resistance is a force which opposes motion.
- **c** All things fall at the same rate if you ignore air resistance.
- **d** A piece of paper falls much more slowly than a brick.

Somewhat different is the process of understanding an argument, that is examining others' arguments to see which support a theory well and which are weaker. Example 4 is typical of this form of exercise.

Example 4: Understanding an argument

Which of the following arguments provide good evidence that matter is made up of particles, and why?

a Air in a syringe can be squeezed.

b All the crystals of any pure substance have the same shape.

c Water in a puddle disappears.

d Paper can be torn into very small pieces.

A common point of argument for scientists is when data are inconclusive and can support two or more views about their interpretation. How does one resolve the situation where there are many varying measurements of the same phenomenon as in Example 5?

Example 5: Experimental data

Everybody in the class measured the boiling point of water. They obtained the following results.

96 ˚C, 94 ˚C, 102 ˚C, 106 ˚C, 108 ˚C, 92 ˚C, 101 ˚C, 86 ˚C, 97 ˚C, 103 ˚C

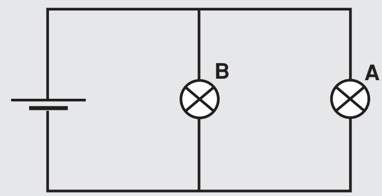
In your group discuss:

a Why might they disagree?

b How might they agree on a value?

Predicting the behaviour of the natural world, and justifying that prediction with the use of argument, can be used to develop the process of arguing. Such a framework of predict, observe and explain (POE) was developed by White and Gunstone (1992). Here a teacher explains to the class the phenomenon he or she is going to demonstrate – such as dropping a heavy and a light object. The pupils are then invited to develop a theory for what they think will happen and why. Such an activity usually generates alternative and competing explanations. In Example 6, pupils are invited to discuss what they think will happen to lamp B when lamp A is disconnected.

Example 6: Predicting, observing and explaining



Bulb A and Bulb B are two identical bulbs.

What will happen to the brightness of lamp B when lamp A is unscrewed?

Discuss in your group and give reasons for what you think will happen.

Strategies for supporting argumentation

Useful as materials such as those described above might be, there is more to introducing argument into science lessons than the production of materials. For any teacher, a learning activity must have a well-defined purpose with objectives that are clear to both themselves and pupils. Pupils need to be encouraged to engage in the processes of arguing such as claiming, justifying, opposing and questioning. Such activity requires work in small groups which is the first organisational challenge for any science teacher interested in pursuing such work. Research shows that **small-group discussion** has not been a strong feature of pedagogic practice in science classrooms (Newton, Driver and Osborne, 1999; Sands, 1981). All the argument activities require that an opportunity be provided for pupils to discuss ideas and evidence. The experience of the teachers working on the project shows that any activity of less than 30 minutes gives insufficient time for pupils to understand the nature of the task, consider the argument, and develop a coherent line of reasoning which they themselves find credible and are prepared to defend.

Whilst the discussion is underway the teacher's role is to act as an initiator of argumentative discussion, using a selection of **arguing prompts** such as:

- Why do you think that?
- What is your reason for that?

- Can you think of another argument for your view?
- Can you think of an argument against your view?
- How do you know?
- What is your evidence?
- Is there another argument for what you believe?

Another strategy is drawn from the literature on teaching pupils to write. Constructing a good argument is not a simple task and pupils need guidance and support which will help to 'scaffold' and build their sense of what is an effective argument. Wray and Lewis (1997) have shown that when such genres of writing or expression are not familiar, **writing frames**, which support the process of writing, can provide vital support and clues as to what is needed. These are essentially drafting documents for recording notes of their discussion which can then be used as the basis for a verbal presentation to the rest of the class or, alternatively, as a structure for producing a written argument. Several variants of these 'writing frames', of which one is shown here, have been developed for supporting argumentation.

My Argument

My idea is that ...

My reasons are that ...

Arguments against my idea might be that ...

I would convince somebody that does not believe me by ...

The evidence I would use to convince them is that ...

Role-plays provide a different strategy whereby the public rehearsal of competing arguments can be used to explore the data and claims used by competing positions. They are valuable in that they can recreate past disputes by introducing the two principal competing alternative arguments at the time and encouraging empathy for those who argued against the new scientific idea. After all, the history of science has shown, time and time again, that human thinking has been dominated by what might be termed the intuitive fallacy – that natural common sense invariably leads to the development of an inappropriate scientific idea. Role-plays of Galileo's arguments with the Church and Darwin's arguments with his opponents are the two archetypal examples. But there are others: Wegener and Plate Tectonics; Pasteur and Pouchet's debate about spontaneous generation of life; Torricelli and the arguments surrounding his evidence for the existence of a vacuum (Charis Project, 2000, see also pp. 71–78 in this issue; Solomon, 1991, 1992).

Finally, group work on argument can lead naturally to **group presentations** where the product of the group's thinking is presented publicly. Pupils can record their arguments on OHTs or posters and outline their thinking. Other groups can then be encouraged to think of critical questions to ask that might oppose the argument they present. This can be structured by asking every other group to discuss the presentation and produce one question. From an argument perspective such activities are significant as they encourage the use of argument followed by critical challenge – activities that both change the audience for whom pupils write and are also essential for developing skills at constructing and defending argument.

Models of arguments

An important aspect of developing an understanding of argument and evidence for pupils is the need to present examples of argument and model good practice. This means offering pupils both weak and strong arguments and discussing the features that make one better than another. Below are two examples of arguments of different quality that could be offered to pupils, of the type we have been sharing with teachers. The first, a weak argument, relies on assertion with minimal use of warrants to justify claims and, moreover, there are no rebuttals of opposing arguments. The stronger argument draws on a wider range of evidence and refutes other arguments. Such examples serve an important illustrative function; just as one picture is worth a thousand words, so is one example of what makes a good argument.

> **Weak argument**
> We must see because light enters the eye. You need light to see by. After all, otherwise we would be able to see in the dark.
>
> **Stronger argument**
> Seeing because light enters the eye makes more sense. We can't see when there is no light at all. If something was coming out of our eyes, we should always be able to see even in the pitch dark. Sunglasses stop something coming in, not something going out. The only reason you have to look towards something to see it is because you need to catch the light coming from that direction. The eye is rather like a camera with a light-sensitive coating at the back which picks up light coming in, not something going out.

Difficulties with argument in the science classroom

It would be absurd to argue that any of these kinds of practice are easy for science teachers. In classrooms dominated by SATs, GCSE results and now schemes of work from QCA, many science teachers may ask two significant questions:

- By exposing pupils to plural alternatives, and even allowing scientifically unacceptable alternatives to be discussed, do we not run the risk of simply reinforcing children's misconceptions? How can we be sure that they have the right answer?
- What will they learn of benefit from this process?

Asked whether they use argument, the following responses were given by a science teacher and a history teacher:

> Science teacher: *Well, discussion all the time. I always start the lesson with a class discussion about what we did last time, what we are going to learn and so on. And group work – I use that a lot but probably not argument. It's more like working together to find the* ***right answer*** *so that they can help each other.*
>
> History teacher: *We are looking at interpretation of what seem to be facts and it's not until they get other evidence that they learn that what they thought were facts ... We set it up so that they think they are getting facts and then we destroy it systematically; it's part of the* ***process****.*
> (Drayton, 1999; emphasis added)

The views of the science teacher show that his/her conception of argument is solely that of a class discussion and its goal is attaining the correct solution. Ideas of process, of how belief relates to evidence, or of 'listening and appraising' are simply subsidiary, or possibly forgotten. In contrast, the history teacher asked the same question has a radically different perspective, one where process rather than content predominates. Whilst the concerns of history and the social world are different from the focus of science – the material world – both are concerned with developing justified, true belief. Over the past twenty years, history teaching has transformed itself, to demonstrate that it is a process of sifting and interpreting evidence to arrive at a defensible interpretation of past events. If one of the distinctive characteristics of science lies in the methods and arguments it uses to support its beliefs, should we not devote more time to considering and demonstrating the foundations of data, warrants and arguments on which scientific knowledge rests?

The significance of argument

Our project is attempting to develop materials and strategies that will enhance both the opportunity and quality of argument in school science. We believe that making the consideration of argument, ideas and evidence a core feature of science education will expose the distinctive character and nature of science. Some may argue that such ideas are acquired along the way, that merely engaging in the process of doing science is sufficient. Sadly, the evidence from research shows otherwise: only explicit teaching about the nature of science leads to any epistemic improvement in pupils' knowledge and understanding (Abd-El-Khalick and Lederman, 2000) – something which our work is attempting to do. The latest version of the science National Curriculum for England provides some recognition of the significance that should be given to 'ideas and evidence in science', with an eponymous strand in Sc1. There is now, for instance, at key stage 3, a requirement that pupils should be taught:

a. about the interplay between empirical questions, evidence and scientific explanations using historical and contemporary examples;

And at key stage 4:

a. how scientific ideas are presented, evaluated and disseminated;

b. how scientific controversies can arise from different ways of interpreting empirical evidence.

It is hard to see how any understanding of controversies can arise if pupils are not presented with alternative views of physical phenomena and given the opportunity to examine the reasons for preferring one to another. In short, science education without argument is like a book without a plot: in danger of becoming a tale told by an idiot, full of sound and fury but ultimately incomprehensible. Science's greatest achievement has been its success as a way of knowing. Its capacity to provide evidence for reliable beliefs has made it one of the paradigmatic discourses in contemporary society, and one to which many other forms of knowledge aspire. Yet contact with school science is insufficient to generate an understanding of how science functions, as some of the central practices of science will be at best glimpsed and often missed. Argument, which is deeply embedded in science, is such a feature.

Much of what we do in science is based on a belief or aspiration that the study of science will produce good analytical thinkers. As Kuhn (1999) points out: '*to achieve control of their own thinking is arguably the most important way in which people both individually and collectively take control of their own lives*'. Some focus on argument, then, would provide an opportunity to practise and develop the reflective analytical skills that are so highly prized in contemporary society. In turn, this would offer science and science teachers a better means of justifying their daily work. For as well as the utilitarian value of science, science teachers could then genuinely claim that they are making a significant contribution to pupils' ability to reason and think critically. Thus our argument is not an argument for argument's sake, but an argument for the sake of school science – an argument with which we hope the reader will concur.

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End-note

Contrary to popular assertion, there are no single photographs that show the Earth spinning. The two pieces of concrete evidence that confirmed the Galilean assertions are Foucault's pendulum and long-exposure photographs taken of the night sky with the camera pointed at the Pole Star. Foucault's pendulum is a very long pendulum suspended on a virtually friction-free pivot (see *SSR* (2001) **82**(300), 119–122). Over the course of the day, the plane of rotation moves. Given that there is no self-evident source of a force that would turn the pendulum, the only satisfactory explanation is that the Earth beneath it is turning. The photographs of the night sky also show that all the stars appear to be going in a circle around the Pole Star. Of the two explanations, (a) that all the stars are going round the Pole Star or (b) the ground on which the camera is sitting is turning, we pick the latter simply because it is the simplest and most plausible.

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