Argumentation in school science: breaking the tradition of authoritative exposition through a pedagogy that promotes discussion and reasoning.

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Abstract

The value of argumentation in science education has become internationally recognised and has been the subject of many research studies in recent years. Successful introduction of argumentation activities in learning contexts involves extending teaching goals beyond the understanding of facts and concepts, to include an emphasis on cognitive and metacognitive processes, epistemic criteria and reasoning. The authors focus on the difficulties inherent in shifting a tradition of teaching from one dominated by authoritative exposition to one that is more dialogic, involving small-group discussion based on tasks that stimulate argumentation. The paper builds on previous research on enhancing the quality of argument in school science, to focus on how argumentation activities have been designed, with appropriate strategies, resources and modelling, for pedagogical purposes. The paper analyses design frameworks, their contexts and lesson plans, to evaluate their potential for enhancing reasoning through foregrounding the processes of argumentation. Examples of classroom dialogue where teachers adopt the frameworks/plans are analysed to show how argumentation processes are scaffolded. The analysis shows that several layers of interpretation are needed and these layers need to be aligned for successful implementation. The analysis serves to highlight the potential and limitations of the design frameworks.

Introduction

Over many years researchers in science education have addressed issues of pedagogic practice in order to optimise students' opportunities for learning in science. In the 1970s and 80s, research was dominated by a constructivist perspective concerned with exploring children's prior knowledge and alternative conceptions in science (Driver & Easley 1978; Driver 1995; Pfundt & Duit 1994; Watt 1998; Harlen 2000), and by the development of models of conceptual change (Posner et al 1982; Strike & Posner 1985; Tyson et al 1997). Application of conceptual change theory and insights provided by constructivist views of learning led to a number of curriculum innovations in science (Driver et al 1994; Nuffield-Chelsea Curriculum Trust 1993) and materials designed for probing understanding (Osborne & Freyburg 1985; White & Gunstone1992; Naylor & Keogh 2000). Constructivist approaches focused either on the domains of science, with materials aimed to address conceptual change in different domains (Simon et al 1994; NPS; Skamp 1998, Naylor & Keogh 2000), or underlying themes such as the role of cognitive conflict, the use of analogies and cooperative learning (Limon 2001). The notion of cognitive conflict derived from the work of Piaget also underpinned science curriculum materials aimed at accelerating reasoning at both secondary and primary ages of schooling (Adey, Shayer & Yates 2001; Adey, Robertson & Venville 2001). The profusion of research outcomes and curriculum materials in this period had limited impact, as the changes required in pedagogy were complex and challenging; to explore students' prior knowledge and reveal their conceptions without clear teaching strategies for building scientific understanding was difficult, particularly when teachers' subject knowledge and confidence were limited (Osborne & Simon, 1996). One of the most notable professional development programmes to accompany an innovation of the 1980s was linked to the cognitive acceleration programmes, where extensive coaching in and out of school over long periods of time did bring about changes in practice and positive effects on students' reasoning (Adey 2004). The wealth of materials produced in this constructivist era has informed our subsequent work, albeit from a different pedagogical perspective, as will be seen later.

In addition to studies of conceptual understanding and reasoning in science, a further line of research in science education has focused on students' ideas about the nature of science and the practice of scientific inquiry (Driver et al 1996, Lederman 2007). Developments in this area have been stimulated by national policy changes in science education, for example the English national curriculum for science and the educational reforms in the USA. This research has more recently converged with studies of students' developing epistemological beliefs (Sandoval 2005; Sandoval & Millwood 2008) and a growing emphasis on the role of argumentation in science education (Driver et al 2000; Duschl & Osborne 2002; Erduran & Jimenez-Aleixandre 2008). A view has now become established that argumentation is a central practice in science and should thus be at the core of science education, and that understanding the norms of scientific argumentation can lead students to understand the epistemological bases of scientific practice. Moreover to provide students with plural accounts of phenomena and evidence that can be deployed in an argument has been shown to lead to a more secure conceptual understanding (Howe et al 2005). Pedagogical materials to develop argumentation in science education are being developed in different contexts and environments, including technology-enhanced learning environments (Bell & Linn 2000; Schwartz & Glassner 2003; Clark et al 2008), inquiry-based programmes (Davis & Krajcik 2005; Krajcik & Reiser 2004) and socio-scientific contexts (Kolsto 2001; Levinson & Turner 2001; Ratcliffe & Grace 2003; Sadler 2004; Walker and Zeidler 2007; Zeidler et al 2009). Alongside these developments in argumentation there has also been a focus on the role of language and talk in students' learning in science (Lemke 1990; Mercer et al 2004, Mortimer & Scott 2003; Simon et al 2008), and pedagogic materials to promote talk (Dawes 2004). The growing focus on dialogic practice (Alexander 2005), where classroom talk that promotes learning is seen as collective, reciprocal, supportive, cumulative and purposeful has influenced our current work on argumentation with teachers, together with studies on the value of small group discussion and collaboration in science learning (Maloney & Simon 2006; Howe & Tolmie 2003).

Though we now have an established body of work on the value of argumentation and small group discussion in science education few studies have attempted to unpack the nuances of task design (Howe & Mercer 2007), as research has tended to focus on evaluating argumentation outcomes (for an overview of many studies, see Erduran & 2008). Previous research undertaken by one of the authors and her colleagues at King's College London set out to develop materials and pedagogical approaches that were designed to enhance the quality of argument in school science (Osborne et al 2004a). These materials were developed by teachers and researchers working together, according to the curriculum needs identified by teachers and their interpretation of the theoretical perspective on argument as presented by the researchers. Teachers were expected to incorporate argument-based lessons approximately once a month during the project. The teachers were initially provided with a set of materials drawn from the literature (see Osborne et al Table 1), then, taking the format of these materials, teachers developed their own resources. An essential precursor to initiating argument in any context is the generation of differences, in science this could take the form of presenting alternative theoretical interpretations of phenomena. Osborne et al used frameworks for developing materials that involved the generation of differences, for example, presenting competing theories for students to examine, discuss and evaluate. In addition to providing such stimulus material, Osborne et al also required teachers to include small group discussion in order to construct arguments justifying their case for one or other theory. As students require data to construct arguments, materials were accompanied by evidence that could be used in support of different theories. In their original research, Osborne et al developed nine generic frameworks from literature sources. The use of generic frameworks was essentially pragmatic, as topics being taught varied from school to school. Osborne et al did not wish to be restrictive or prescriptive, but rather they encouraged teachers to develop their own ideas and develop lessons around the frameworks. To determine the extent to which teachers' practice in the use of argumentation developed over a one-year period, lesson transcripts taken before and after the period of intervention with monthly argumentation lessons were analysed and compared. Results showed that for some teachers the complexity of argumentation in the classroom was enhanced, as the discourse was found to include more extended arguments incorporating backings and rebuttals (Toulmin 1958, Erduran et al 2004). Some teachers also developed more effective ways for scaffolding the processes of argumentation through encouragement of talking, listening, justifying, counter-arguing and reflecting (Simon et al 2006).

Building on this original research, Osborne et al continued to work with teachers to develop training materials that would help other teachers to practice the skills needed to implement argumentation (IDEAS pack by Osborne et al 2004b). The training materials included a set of six training sessions and 28 video clips of teachers enacting activities. The INSET sessions focused on pedagogical processes such as groupwork strategies, ways of introducing, sustaining and rounding off an argument activity, evaluating argument, modeling and counter-argument. These sessions were accompanied by a resource of 15 lessons that incorporated a variety of the frameworks, including examples based on the frameworks introduced in the original research. These resources were to include additional details for teachers, based on the assumption that further advice was needed in addition to the frameworks for successful implementation. Though each activity is set in a particular science context, it was assumed that teachers could use the framework to plan activities in other topics. In doing so the pack introduced a series of 'layers' for further interpretation that involved the teaching goals, science content, lesson procedures, student resources, groupwork strategies and guidance about the teacher's role.

Since the publication of IDEAS, the materials have been adopted worldwide and translated into many languages. Yet there remains an ongoing question about their interpretation that in our view requires further analysis to inform the wider application of these kinds of activities in the classroom. In this paper we address several questions. What do the frameworks offer? How can different scientific contexts be used with each framework? How can the framework/context be planned to focus on reasoning, extending the range of goals for teachers in the classroom? In practice, how do these aspects align to optimize teaching?

We begin by establishing the theoretical positions that inform the work, including our perspective on argumentation and the role of small group discussion. In our analysis of task design we focus on the layers of interpretation, including the design framework, the science context used, lesson planning and the teacher's role. We review some of the frameworks and lesson plans from the IDEAS pack, and raise questions that will inform us in future research with teachers about the complexity of planning involved in designing an activity and carrying it out in the classroom.

Theoretical framework

A perspective on teaching argumentation

The research on argumentation undertaken by the King's group that culminated in the production of the IDEAS materials built on a wealth of previous research that has continued to grow (Erduran & Jimenez-Aleixandre 2008). Of particular significance to the thinking behind the work was the contribution of Kuhn (1991) who explored the basic capacity of individuals to use reasoned argument. Kuhn's work highlights the fact that the use of valid argument does not come naturally, but is acquired through practice. In orther words, argument is a form of discourse that needs to be appropriated by children and explicitly taught through suitable instruction, task structuring and modeling. Just giving students scientific or socio-scientific issues to discuss is not sufficient for them to construct valid arguments (Osborne et al 2004a). Hence the focus of the work was to develop pedagogical practices that support argumentation and foster students' epistemological development. In doing so Osborne et al addressed a number of questions, such as, how could teachers assist students in developing their reasoning? How could they identify the essential features of an argument? Also, how could they model arguments of quality for their students? In order to provide some theoretical guidance to answer these questions, the team chose to use the analytical framework developed by Toulmin (1958). For Toulmin, the essential elements of arguments are claims, data, warrants and backings. A claim is an assertion that is believed to be true, which relies on evidence or justifications that consist of data related to the claim by a warrant. Warrants may depend on a set of underlying assumptions, or backings, which may be implicit. Arguments are also hedged by qualifiers that show the limits of the validity of the claim, and can be rebutted by counter-arguments that challenge the data, warrants or backings. Toulmin's model had previously been adopted by other researchers for characterizing argumentation in science education, and the King's team developed its use further to focus on the reasoning functions and strategies used by students (Erduran et al 2004).

The INSET materials produced for teachers within IDEAS are underpinned by these theoretical perspectives and the training sessions draw explicitly on Toulmin's model. Yet in constructing the classroom activities based on the design frameworks, to be used in conjunction with the training sessions, other theoretical perspectives less clearly identified and articulated have also influenced the presentation for teachers. For example, many activities have conceptual as well as epistemic goals. Though more recent work has focused on these as outcomes of argumentation (von Aufschneider et al 2008), the design of the IDEAS resources was more concerned with producing engaging materials for setting up argumentation processes. Our view is that task design needs to address the fact that teachers may not have a clear perspective or rationale for argument and their main motivation for adopting IDEAS resources might be for engagement rather than for developing reasoning or conceptual understanding. More recently, other researchers are addressing these issues of task design more overtly, for example, Asterchan & Schwartz (2007) propose that engaging in argumentation by producing reasoned arguments in favour or against one's own or another's views facilitates concept learning, so they have designed tasks within a 'cognitive conflict' paradigm, where students are either presented with anomalous data, or paired with peers having different views.

The role of discussion and collaboration

Prior to the Osborne et al study, there was evidence to suggest that argumentation is fostered in a context in which student-student interaction is permitted and encouraged (Alverman et al 1995; Jimenez-Aleizandre et al 2000; Kuhn, Shaw & Felton, 1997, Zohar & Nemet, 2002). Osborne et al therefore worked to establish strategies that promote dialogic discourse, considering the social structures of the classroom when designing activities that foster argumentation. The teaching strategies that were developed and incorporated within IDEAS include guidelines for organizing and managing small group discussion, the use of pair-work, triads, envoys, presentations and debates to facilitate talk between students. The importance of dialogic practice and collaborative working has been emphasized more recently by Howe and Mercer (2007), who take a socio-cultural perspective that learning is determined by social and communicative interactions that reflect the cultural values surrounding schools and classrooms. Supported by reference other studies, for example, collaborative reasoning (Anderson et al 1998), Howe and Mercer show that features of exploratory talk, where children share knowledge, challenge ideas, evaluate evidence and consider options in a reasoned and equitable fashion do promote learning. Yet the design of appropriate tasks requires an understanding of how such talk can be generated productively. Howe and Mercer identify three key considerations in task design, first, that members of the group must believe that all their contributions are important, second, that the task depends on a group effort requiring resources that all have to contribute, third that tasks are challenging relevant to current understanding. Moreover, Howe's work (ref) has also shown that the aspect of task design relating to student outcome, that is whether consensus is required or not, how positions are recorded, influences patterns of interaction in the activity. Howe and Mercer conclude that task design is in its ‘infancy’ at present and that further developments will help to clarify why classroom dialogue remains unproductive, or highly monologic (Alexander 2005). They suggest that teachers rarely make explicit the kinds of interactions they expect to take place in group discussion, even when they give explicit instructions to ‘talk together to decide’ or ‘discuss this in your groups’. Thus in developing activities that promote productive interactions involving argumentation, we need to help teachers understand the complexity of task design.

Designing tasks – layers of interpretation

In collecting together the resources developed by teachers and presenting them as planned activities in the IDEAS resources pack, Osborne et al hoped that teachers could choose a framework or activity and be able to adapt it for use in different science contexts. Yet to plan a lesson in a new science context using a generic framework or sample activity is a complex task; it involves an articulation of goals and clearly thought out procedures that involve ‘imagining’ the lesson and how the activity might proceed with the class; it involves thinking about how the lesson begins, how the students are organized to facilitate small group discussion, how the science will be addressed through the resources used, what role the teacher will take as the activity proceeds, how the activity will come to an end and how the science, the positions, the evidence will all be resolved to achieve the goals. In analyzing our IDEAS resources we therefore look at all these layers of interpretation, focusing on the reasoning that the activities can facilitate through the frameworks, the science, the planning, the resources, and finally the enactment as portrayed by the teachers who designed the tasks.

Design frameworks

In our analysis of design frameworks we have chosen to focus on three frameworks that have either been widely cited in the literature or used by teachers working with the materials to enhance conceptual as well as epistemic understanding. These frameworks include classification, competing theories and Predict-Observe-Explain (POE).

The reasoning involved in classification activities can be analysed in terms of Piagetian operations, as was done by Shayer and Adey in describing and measuring cognitive development in the cognitive acceleration in science education (CASE) research (Shayer & Adey 1981; Adey & Shayer 1994). Simple classification that puts objects into groups according to a given criterion is indicative of concrete reasoning, but to see that this is only one of many possible ways in which classification might be carried out requires formal or more abstract reasoning. More complex classifications systems use more than one criterion at a time to group objects into several categories. To be able to see whether a classification operation involves inclusion or exclusion and is part of a hierarchy requires formal operational thinking. Argumentation activities that use a classification framework would need to involve this level of complexity in order to create the differences required for categorization. Our analysis of the classification activities in IDEAS is informed by this perspective.

The design frameworks that involve analyzing, evaluating and arguing for a position with regard to competing theories arise from the literature on children's ideas in science and conceptual change. Popular examples that are included in the pack are derived from concept cartoons (Naylor & Keogh 2000), where children express alternative explanations as speech bubbles for a phenomenon represented in pictorial form (see Appendix 1). This articulation of alternative ideas by 'other' children serves to stimulate different positions of students studying the cartoon, encouraging them to find reasons to justify alternative views. Competing theories can also take the form of alternative statements about a phenomenon accompanied by evidence statements that may support one statement, the other, both, or neither. Students are asked to consider each piece of evidence and evaluate its role and significance, then use the evidence to argue for one statement or the other. The difference between the two types of competing theory framework lies in the sources of evidence that students are able to use to construct arguments for their positions, which can have implications for the kind of reasoning and complexity of argumentation.

Predict Observe Explain (POE) activities were drawn originally from the work of White and Gunstone (1992). Students are introduced to a phenomenon and asked to predict what will happen when a demonstration of the phenomenon takes place (see Appendix 2). Differences arise from different predictions, and argumentation ensues from the need to justify predictions. Once the phenomenon has been demonstrated students can discuss their predictions in order to change their minds or consolidate their position. The act of explanation involves reasoning using warrants and backings to justify the use of evidence to support a claim.

Analysis of the frameworks alone does not provide a sufficient indication of how they will work in practice – the science contexts in which they are set, plus the plan of how to put them into action, are critical factors, as are the teachers' interpretation, introduction and interaction.

The science

In our work with teachers we are often requested to help them find an appropriate argumentation task for their current curriculum topic. Yet the science context for any particular design needs careful thought. Indeed Asterhan and Schwartz (2007)in their experimental design carefully chose a topic, evolution, that would have features relevant to facilitating dialogic argumentation, that is, it is a complex concept requiring the integration of different explanatory schemas, and students may draw on different schemas to construct explanations for different evolutionary events. Asterchan & Schwartz are rather dismissive of scientific concepts such as mass or light as a means for promoting dialogic argumentation, suggesting that these topics would benefit more from hypothesis-testing strategies, our concern is therefore to look more closely at IDEAS activities that focus on such topics and ask whether they are appropriate science contexts to promote argumentation.

The lesson plan

The lesson plans that have been constructed in the IDEAS resources pack follow a similar format of aim, learning goals, teaching points, teaching sequence and background notes, with master copies of student materials. This format is similar to other types of teacher guidance, for example *Thinking Science* (Adey et al 2001) the materials from the CASE project and *Twenty First Century Science* (University of York and Nuffield Foundation 2006) follow similar formats. In our analysis we unpack the nuances within the IDEAS plans, focusing on the ways in which they need an interpretation on the part of the teacher to put them in to practice in order for reasoning to be initiated and promoted in the discourse of the classroom.

The enactment

Our focus on enactment of the IDEAS activities is grounded in the original research on teachers' use of strategies and scaffolding of argumentation processes (Simon et al 2006). The analysis of lesson transcripts focused on teachers' oral contributions that facilitated argumentation processes, as these were identified as reflecting implicit goals (Table 1). For example, where teachers' talk encouraged students to make contributions and listen to other students, this reflected a goal on the part of the teacher of 'talking and listening', that is, the processes of talking and listening were seen as important social aspects to foster argumentation. A further example is that of prompting justification, where teacher talk that asks students to provide reasons for their claims shows that the teacher places importance on justifying claims with evidence. The argumentation processes shown in Table 1, together with the focus of each INSET area, served to frame our analysis of enactments in terms of their potential for facilitating argumentation. Osborne et al (2004a) also developed writing frames, model arguments and structures through which argumentation could be scaffolded, called argument prompts, such as 'Why do you think that?', 'Can you think of another argument for your view?', 'Can you think of an argument against your view?', 'How do you know?' Our analysis of enactment also focuses on these prompts.

[Insert Table 1]

Other attempts to promote scaffolding of argumentation (Asterhan and Schwartz 2007) have involved similar kinds of prompts as those developed in IDEAS. In one study participants were given explicit instructions to argue for different positions using an in-depth critical discussion, to provide justifications, to persuade each other why one position might be better than another. They were provided with questions such as 'Why is your claim true?', 'Why is a certain idea or solution incorrect?', 'Can you provide evidence for your claim?' Can you prove the incorrectness or weakness of a certain argument or solution?', 'What are the weaknesses in your or your partner's arguments?', 'To what extent do the justification, the proof and the explanations really support the proposed claim?'. These participants were also provided with an exemplar of a critical discussion similar to the IDEAS model argument.

Task Analysis

Our analysis of the resources (lesson plans) within the IDEAS materials has been in terms of the layers outlined above. It is our contention that teachers' interpretations of each layer hold the key to successful implementation, therefore to unpack our guidance for teachers will serve to highlight problems and issues that we can address in our future work. We have chosen to look closely at examples from three frameworks, first discussing the framework as presented in the plan, then the resource itself and processes involved. Finally we focus on examples from lessons as they were enacted by teachers who designed them. The aim of our analysis is to show how the three main components have been designed to fit together – framework, science and lesson plan. The examples from the classroom serve to illustrate the potential, with limitations, of these plans.

Framework: Classification

A classification framework offers many opportunities for argumentation. At the simplest level, classification entails choosing a category from multiple options, which implies the need to justify that choice when challenged. Going deeper, the use of controversial or 'edge' cases in which the object displays some characteristics of different categories can trigger counterarguments, as the evidence is not entirely in concord with itself. Different pieces of data which clearly relate to different categories (for example, an organism has a cell wall like a plant, but feeds like an animal) encourage students to select data to support a claim or attack a counterclaim, and to consider the relative importance of different pieces of evidence. In other cases, the same piece of data may be interpreted differently by students to support opposing categories. For example, the data 'Euglena is green' can be interpreted through the warrant 'like a frog' to be classified as an animal, or through the warrant 'so contains chlorophyll' to be classified as a plant. This introduces the importance of warrants as the connection between data and claim. When irrelevant data which does not help to discriminate between categories is included, this highlights the point that not all information is evidence – it only becomes so when it is incorporated into an explanatory framework (Koslowski et al, 2008). Both of the resources below take advantage of controversial cases and irrelevant evidence.

Science example: Euglena

Euglena is a single-celled organism which shows some characteristics of both plant and animal cells. Students are asked to apply their knowledge of typical characteristics of plant and animal cells in order to categorise this particular cell. This challenges students' conceptions at two levels. Firstly, real cells often do not provide a perfect match for the stylised cells that students learn about. Secondly, Euglena is an organism within the taxonomy of living things which is neither plant nor animal. This provides a useful 'edge' case, which test the deductive taxonomy, and so can extend pupils' understanding of the features of plant and animal cells, and force them to consider which features are most important in classification. Depending on how the teacher approaches the revelation of Euglena as a protista, the activity may also allow pupils to consider how observations of unknown cells may lead to changes in taxonomy, or the natural limitations of any taxonomic model.

Science example: Sedna

The Sedna activity is not founded on specific curriculum knowledge focusing instead on contemporary astronomy to model the messy process of classification when boundaries are unclear. This resource was created before ‘planet’ was defined, and so offers an insight into a more inductive form of classification (compared with the Euglena resource) where objects are grouped by implicit and unarticulated similarities. Therefore, it may encourage pupils to begin articulating criteria for their categorisations, and then to reflect on how these criteria can be justified against the criteria of other groups.

As the Sedna activity was derived from the Euglena activity, both resources use a grid on which students arrange evidence cards. Each includes empirical data as evidence such as observed features of Euglena and Sedna, and also other forms of evidence, such as the views of scientists. This is useful for conveying the multi-faceted nature of the evidence which scientists work with, and also for encouraging pupils to discriminate between different sorts of evidence.

Both resources follow the same lesson format and have similar teaching notes. The introductory activity focuses on raising pupil interest in the question, in order to foster discussion. Students are then asked to sort evidence cards (see Appendix 3) into different columns to show which classification each card supports. During this, the teacher is asked to probe reasoning to identify the connection between the evidence card and the claim (eliciting warrants). They should also identify data which can rebut a particular classification, and ask pupils to respond to this rebuttal. Finally, the teacher chooses opposing groups to report, and encourages pupils to rebut claims with data. In these activities, both teachers and students focus on *counterargument by providing contradictory data*.

At the end of the lesson, teachers are asked to reveal that the ‘edge case’ could not be classified within the existing system by scientists. This highlights a tension in task design between providing a task with genuine controversy which will motivate discussion, and providing a task which the students have no way of completing successfully, which may demotivate discussion.

Enactment: Alex

Alex introduces the lesson by drawing students’ attention to a flask of water (she holds it up) in which there are what she describes ‘little friends called Eugene’, and suggests to the students that they probably cannot see them. She then projects them on to a screen so that they can be seen them swimming around. This introduction serves to capture students’ attention to something living that they can see and be curious about. She then asks the students to describe what they can see, adding the phrase ‘what is an observable piece of evidence about the Eugenes?'. This statement not only invites the students to observe and make a contribution but also begins to introduce the language of scientific reasoning. As children make observations Alex rephrases their answers but limits her evaluation of their responses, as she does not want to close down the discussion but invite further contribution. As students become interested they ask 'what is it?', and Alex describes it as a 'single cell called Euglena', being cautious not to pre-empt the classification process. She draws attention to Euglena's movements, encouraging the students to observe more features, asking them again 'what can we say about them?'. As students observe 'green bits' and 'swim very fast' Alex praises them. These are the characteristics she hopes they will use in their decision-making about classification. When a student asks the question 'is it a plant', Alex responds with 'well there is a question', and asks the students why it might be a plant. Throughout this introductory episode she is aware of her goals that focus on argumentation about classification, and the discourse is therefore open, exploratory and dialogic, rather than closed in search of the 'right answer'.

After a range of observations and questions, Alex introduced the students' task and resources. She has prepared cards with evidence statements, a diagram of Euglena and a template to hold up for the students so that she can give them instructions about the procedures, and she has organised the students into groups of four. She draws attention to some of the evidence statements, modelling the process the students will undertake by reading some of the cards, discussing what the statements mean, and choosing where the cards should be placed on the template by deciding whether the evidence supports a classification of plant, animal or neither. Whilst the students carry out the task Alex moves from group to group, supplying extra textual information about cells for those who struggle with understanding the meaning of the statements, for example, 'Euglena contains cytoplasm'.

When the students have finished choosing where to place the cards, and have decided whether Euglena is plant, animal or neither, Alex conducts a whole- class plenary and asks for a class vote on their decision ('who thinks plant?' etc). She then asks students to explain their decisions, drawing out the arguments that have been constructed based on the evidence statements. She uses the students' answers to draw their attention to further features (represented in the diagram) of Euglena, so that they question more deeply the evidence base for their decisions. She then asks if anyone has changed their mind, having heard all the arguments. This episode allows the students to express their decision in a concise but inclusive way (voting), to articulate their thinking, and to listen to other ideas and reflect on their own arguments. Alex then introduces the idea that Euglena is neither plant nor animal, but a protista, so that students extend their understanding of biological classification through the cognitive conflict arising from this alternative position.

Framework: Competing theories

Many frameworks involve selecting and justifying a correct answer from several alternatives. Research into students' ability to move on from initial incorrect ideas has produced mixed results, but this process may be scaffolded by presenting alternatives.

Howe and Mercer (2007) demonstrated that groups of pupils integrate two concepts to produce a higher-level concept in less than 0.1% of observed conversations. However, Smith et al (2009) found that undergraduates can jointly select the correct answer from a multiple-choice question even when none of the group initially knew the correct answer. One mechanism which could explain this is that the students are pooling their knowledge about incorrect answers to arrive at the correct answer through a process of elimination. For example, a group of three who each know that a different answer is incorrect can collaboratively select the correct answer. However, does this equate to the improved conceptual understanding which these activities intend? If distractors and alternative theories match pupils' own ideas, then an understanding of why these are wrong will certainly improve conceptual understanding.

Another presupposition of competing theories is that students will frame the theories as competing. This will depend on student factors such as their epistemology and prior knowledge of topic, as well as on factors inherent to the nature of the two theories. For example, in *Phases of the Moon*, students may accept that both clouds and shrinking and expanding contribute to the change in shape that we observe, as they do not contradict each other.

Science example: Phases of the Moon

The phases of the moon are caused by the relative position of the Earth, moon and sun. This is expected knowledge at primary school level, but is often poorly understood and explained by secondary pupils, as it requires mental manipulation of several bodies with respect to each other. Further, it can be confused with several other astronomical explanations which are familiar to pupils, such as the explanations of the seasons, or night and day, or the apparent movement of the sun. Classroom dialogue, accompanied by empirical observations of the moon's shape, can help students to re-examine and change their ideas about the cause of lunar phases (Sherrod and Wilhelm 2009). This resource offers students an opportunity to select from a range of explanations and argue against incorrect ones. The main focus of counterargument is *counterargument by implication*, where students will suggest that if Theory A were true, then B would be observed, and B is not observed. For example, if the Moon was blocked with clouds, then the shape of the moon would only depend on the weather, but it can appear the same shape in different types of weather. This is quite a sophisticated level of counterargument, as it depends on reasoning with counterfactuals. It is therefore better suited to students with some prior experience of argument.

Five explanations for the Moon's changing shape are given, each of which have different implications for the shapes which would be observed (see Appendix 4). Students are also provided with a writing frame, which asks them to identify the best argument and justify their choice. It then asks them to say why the other explanations are 'not so good or wrong'. This resource explicitly encourages both justification and counterargument.

The lesson plan and teaching notes for this activity are quite sparse, perhaps because the resource itself provides an obvious structure for the lesson. The suggested starting point is checking pupils' understanding of the phases of the moon, as this will be a crucial evidence base for the activity. Students are then asked to work in groups of four or five to choose the best explanation, justify their choice and argue against the other explanations. While it may be useful for students to pool ideas about the explanations, this seems a large group size for a discussion when there are no particular roles for students to adopt, and may hinder the active participation of all students in constructing counterarguments. The suggested plenary involves going through each explanation and choosing groups to argue for and against it. This may allow students to engage with other stances in practice, rather than simply anticipating counterarguments (which may not match the actual counterarguments presented).

Science example: Snowman

Will a snowman melt faster if he is wrapped in a coat? The melting rate of a snowman depends on multiple processes of heat transfer, each affected by a number of factors such as surface area, surface colour and air temperature. This activity therefore represents a genuine ill-structured problem, in which uncertainty is high and a number of factors must be considered. It can be argued that argumentation here is at least as important as empirical inquiry for establishing a general principle, as the latter would only provide data for a specific set of circumstances, and theoretical understanding of conduction, convection, radiation and evaporation is vital for understanding the likely outcomes under a range of circumstances.

The resource includes a concept cartoon with two snowmen (one with a coat and one without, see Appendix 5) with different explanations of why each will melt first. This cartoon is accompanied by questions which elicit first a choice of stance and justification, and then an analysis of one argument. There is also a set of evidence statements which can be used to improve one argument, which includes a number of incorrect statements. This resource therefore encompasses many aspects of constructing argument: taking stances, justification, evaluating arguments, and using evidence to improve argument.

This lesson plan explicitly suggests the pairs-to-fours groupwork strategy as a way of structuring discussion. Students are asked to write an initial argument in pairs, then share their ideas in fours before being presented with additional evidence to help improve their argument. The lesson structure clearly follows constructivist principles by beginning with elicitation of students' ideas about a phenomenon, before extending those ideas through discussion and presenting further information. The suggested plenary involves presenting these group arguments to the whole class, with the teacher focusing on encouraging pupil questions and counterarguments, and noting differences in ideas and reasoning. This allows access to further argumentation skills which are not explicitly scaffolded by the resource itself.

Enactment: Sue

Sue introduces her argumentation lesson by reviewing 'how to make and structure a good argument'. She asks her students what makes a convincing argument and uses a projector to record the students' ideas for all the class to see. She responds to contributions with further questions, for example, when a student says ‘evidence’ she asks ‘why do you need evidence?’. Sue also asks the students how they should consider disagreements, encouraging them to anticipate counter-arguments and explaining what these mean. Sue then introduces her worksheet depicting the two snowmen, calling them Fred (no coat) and Birt (coat), she reads out the caption under each snowman that states reasons why he thinks he will melt first. She then asks the students to discuss their choice of which snowman they agree with, giving their own reasons why they think he will melt first. The introduction of two alternative choices, each with reasoned arguments, serves to stimulate not only the process of justifying a choice, but of constructing counter-arguments against the alternative. Sue refers back to the her summary on the projector to encourage the students to use facts, evidence and reasons in their argumentation.

As the students discuss the alternatives in small groups, Sue listens to their ideas and occasionally interjects her own counter-argument, we call this ‘playing devil’s advocate’, so that the students are encouraged to argue strongly for their choice and against the alternative. She uses scientific language in her responses, for example, transfer of energy, and encourages each group to reach a consensus once they have considered alternative arguments, using scientific reasons to justify their choice. Once each group has made a preliminary choice, Sue conducts a whole class plenary, drawing on the choices and reasons from different groups. She uses their responses to draw out scientific ideas, such as insulation. This small plenary serves to expose all the class to the ideas articulated in each group. Sue then provides an opportunity for each group to construct an ‘improved’ argument, for which she provides a writing frame that can be presented in a subsequent plenary. In this plenary, she encourages the students to compare each others’ arguments, in terms of content and strength of scientific reasoning. Sue shows higher order teaching skills in this lesson of evaluating argument, counter-argument and reflecting (Simon et al 2006), and so a film of this lesson is used frequently to help other teachers analyse these processes in action.

Framework: Predict, Observe, Explain

The predict-observe-explain structure aims to introduce new evidence, which may create conflict with existing beliefs. The structure therefore explicitly involves reflecting on ideas in the light of evidence, which is often left out of more open activities. It emphasises the empirical nature of science, specifically the central role of data in changing theories.

The major difficulty with POE is that it relies on the observation ‘working’ (people seeing what is actually there and the demonstration ‘working’) and it implies that observations are sufficient to create explanations. This latter perpetuates an image of science in which ideas are simply tested so that correct theories will ‘fall out’ from experiments without any need for interpretation. In contrast, work on confirmation bias (Zeidler, 1997) consistently shows that students will interpret data in the light of pre-existing theoretical commitments, by discounting contradictory evidence as erroneous, accommodating the evidence so that it supports the theory, or even failing to notice it. Historically, the coordination of theory and evidence by scientists often discounts empirical results as erroneous, so this skeptical approach to data is not necessarily undesirable in students.

Science Example: Circuits

In this activity, students are provided with three pictures of circuits (see Appendix 6), a prediction box, a tickbox question to show which bulb was brightest in practice, and an explanation box to explain any discrepancy between prediction and observation. Electrical circuits with two cells will only function if the cells are arranged in a particular orientation (+/-/+/-) or (-/+/-/+). This is because electric current only flows through cells in one direction. For a circuit containing two cells, there are four possible orientations in space, only two of which will function. It is surprising that students are only given three of these circuits to discuss, as this is insufficient to distinguish the empirical rule which determines whether the bulb will light.

Firstly, students are asked to predict what will happen in each circuit, and justify their answers. This encourages justification, and also counterargument from justifying the opposite claim, as students are likely to disagree on which circuits will work. Students are then asked to reach agreement on a prediction, although no specific guidance is given on how to reach a consensus. This is particular difficult without empirical evidence, so groupwork strategies such as listening triads might be useful for elaborating on ideas. Students are then asked to build the relevant circuits to test their ideas, while the teacher probes their justification for what they have seen. In this framework, the claim is actually an empirical observation 'the bulb lights/does not light' and the data and warrant are ideas which explain this (for example, the flow of current). The final stage of the lesson requires students to recognise conflict between their predictions and their observations, with the implication that observations triumph over prediction. This is particularly brave given the usual proportion of broken bulbs, faulty wires and failing cells in a school circuits kit.

A particular issue with this POE activity is that it does not deepen conceptual understanding – by the end, pupils will have learnt an observational rule but not how flowing current relates to charge. It is not clear that discussion contributes much in this activity.

Since the publication of IDEAS, to our knowledge no-one has used this activity in the resources pack, our analysis suggests how it is problematic and reveals the thinking needed in design.

Science Example: A Burning Candle

When a candle is placed under a jar, the flame is extinguished after a short amount of time. If this jar is submerged in water, the water level in the jar will go down as the jar is placed over the candle, and then rise as the flame is extinguished. The explanation for this observation is disputed. While the demonstration was traditionally used to show that the flame is extinguished when the oxygen in the jar has been consumed, others have posited that the flame is extinguished because carbon dioxide is produced and sinks down to the level of the flame, cutting off the oxygen supply. Students are provided with a picture of the demonstration set-up (see Appepndix 2), and a structured question sheet: What do you think will happen? Why do you think this will happen? What happens when it is demonstrated? Explain why you think what you observed happened.

Students are expected to have some prior knowledge about objects burning in air, and so the first activity aims to elicit some alternative hypotheses and for students to commit to a particular prediction and provide a justification. Students are then asked to watch the demonstration and record their own observations. They then work in groups to compare predictions, observations, and explanations, and to identify discrepancies between predictions and explanations. This offers an opportunity for students to reflect on their own reasoning in predictions. The session is then capped with a whole-class discussion, emphasising different explanations and rebuttals based on reasoning: ‘Does anyone want to suggest why they think that might be wrong?’. Compared with the Circuits lesson, this structure offers more opportunities for students to compare ideas with each other, counter-argue, and reflect on and improve their own reasoning. It is therefore more likely to help students develop higher-order argumentation skills such as evaluation, counterargument and reflection.

Further, this POE activity acknowledges the problematic nature of supporting a theory with empirical evidence, as multiple theories are consistent with the evidence available.

Again we have no examples of enactment of this activity to date, but some teachers have expressed an interest in trying it out once other activities have been attempted. The activity requires confident subject knowledge to evaluate different explanations of the science.

Discussion

The design frameworks of the IDEAS resources were provided for teachers because (1) it was impractical to provide lessons for every topic and (2) teacher ownership in adapting the lessons will help to prompt thought about learning goals. However, while concretising the frameworks in the form of resources makes them more accessible, it obscures their pedagogical intentions. The INSET sessions do place some emphasis on broadening teaching goals from a traditional focus on content, to include cognitive, epistemic and social goals, but the resources do not explicitly encourage teachers to analyse the argumentation processes embedded within different activities, and how to adapt the argumentation to achieve different goals. In presenting resources that can be used directly, we have not invited teachers to analyse the processes involved, that is, in terms of reasoning demand, science content, group dynamics and all the argumentation processes identified by Simon et al (Table 1). Presenting teachers with readily usable resources rests on an assumption that development comes from practicing specific processes. Without a more informed basis for analysing and reflecting on the activities, argumentation can become a frozen skill set which can be ‘applied’ to different content, but in which students do not specifically develop their skills. Our concern therefore is with the question of *how* teachers construct activities from such resources that will enable students to develop their argumentation. The lesson plans in the Resources pack are intended to help teachers shift from traditional modes of teaching using authoritative exposition to more dialogic practice, but the decision-making involved requires an interpretation of the framework, science, plan and enactment that can be complex and challenging.

We suggest that a more analytical approach to planning activities is necessary to fulfil one of the potential purposes of argumentation, that is, to improve students' understanding of the nature of science. In argumentation, this is typically achieved through students experiencing the tentative and argumentative nature of science as they grapple with coordinating theory and evidence in these activities. This provides a more tacit alternative to curricular approaches which aim to present students with propositional statements and examples about the nature of science. However, since the nature of science and the nature of thinking are both contested, multi-faceted and complex, it is unsurprising that no single argumentation activity wholly does justice to these concepts. The important thing is to be aware of how each activity contributes to cognition and to students' understanding of scientific reasoning, and to use a mixture of activities so that students have a 'balanced diet of argumentation'. Having development a procedure for analyzing the layers of interpretation within each activity, our next task would be to develop an analytical tool for teachers to perform a similar task on a range of activities. In this way we would not only hope to assist the depth of planning needed, but also provide teachers with a means for creating and adapting a range of tasks that would address a wider set of teaching goals.

Our analysis of resources has also helped us to consider the ways in which group dynamics should be considered for different pedagogical purposes. There are three main roles that a pupil group can perform in the task design. In the first, the purpose of the group is to create an uncomfortable conflict or difference which provokes discussion, either because pupils already have different ideas from each other, or because they are assigned different stances/roles/evidence. The aim of the activity is then to explore and often to resolve this difference. Teachers can support this conflict creation by requiring an initial individual commitment (as with POE) to prevent automatic agreement with the first speaker. However, social multiplism (where students adopt a multiplist epistemology by arguing that all opinions are equally valid, in order to maintain social harmony) can still threaten exploratory discussion. The second possible purpose is to share knowledge and experience in order to solve a problem. For example, in activities which require pupils to rebut a number of alternative theories (such as Phases of the Moon), pupils pool their ideas to construct the best counterarguments. Here, pupils are less likely to take opposing stances. Teachers can support this process by ensuring that pupils do actually have different knowledge from each other, for example through teaching preliminary activities in jigsaw groups or grouping pupils according to previous assessment. It is essential in these cases that no student can solve the problem individually, as this undermines students' sense of groupwork as valuable, and also leads to situations in which students are left to 'discuss' something which doesnot need discussion, which can lead to off-task behaviour. Finally, the pupil group can act as a prompt for informal externalisations of thought. Here the group is a relatively passive audience which scaffolds the process between thinking and formal writing by allowing individuals to ‘think it through’ out loud.

Conclusion

We set out to address some fundamental questions about the IDEAS resources that we feel are necessary in understanding the potential offered for students’ scientific reasoning and the limitations that restrict effective implementation of argumentation activities. Our conclusion with respect to the frameworks is that some work better than others because they do stimulate the kinds of reasoning (e.g. classification) that are essential for developing scientific understanding. All three frameworks we have considered are appropriate for use in different science contexts, but the guidance for some shows that they may have limited opportunities for collaborative reasoning (circuits). In examining the different layers of interpretation needed we have demonstrated the complexity involved in framework, science and lesson plan that faces teachers as they implement an activity. We suggest that successful alignment of these layers can only be achieved if teachers have a good understanding of how the framework/science and lesson plan work together in creating an environment in which argumentation can thrive and scientific reasoning be developed.

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Table 1

Codes and Categories for Argumentation Processes, Arranged in a Tentative Hierarchy

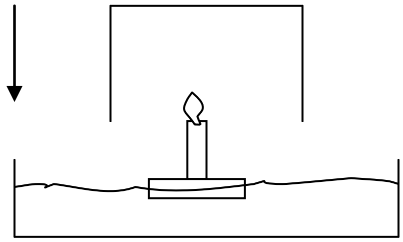
Codes for Teacher Utterances that Reflect Goals for Argumentation	**Categories of Argumentation Processes as Reflected in Teacher Utterances**
Encourages discussion Encourages listening	Talking and listening
Defines argument Exemplifies argument	Knowing meaning of argument
Encourages ideas Encourages positioning Values different positions	Positioning
Checks evidence Provides evidence Prompts justification Emphasises justification Encourages further justification Plays devil's advocate	Justifying with evidence
Uses writing frame or written work/prepares presentations/gives roles	Constructing arguments
Encourages evaluation Evaluates arguments process – using evidence content – nature of evidence	Evaluating arguments
Encourages anticipating counter-argument Encourages debate (through role play)	Counter-arguing/debating
Encourages reflection Asks about mind-change	Reflecting on argument process

Appendix 1


Don't put the coat on the snowman. It will melt him
I don't think the coat will make any difference
It will keep him cold and stop him melting

Appendix 2

What will happen when the candle is covered?



What do you think will happen?

Appendix 3

Euglena Evidence Cards

Euglena does not have a cell wall	*Euglena* contains chloroplasts
Euglena has a nucleus	*Euglena* is a single cell organism
Euglena can absorb food from its surrounding	*Euglena* confused early scientists
Euglena is normally green	The nucleus contains DNA and controls the cell activities
Chroloplasts enable a cell to photosynthesize	A vacuole controls the amount of liquid in a cell
Euglena swims through Water	*Euglena* can make its own food

Appendix 4

Phases of the Moon

Most people who have looked up in the sky and seen the Moon notice that it does not always have the same shape. Scientists say that the Moon has different phases. Many adults however cannot explain why the Moon has different phases. The following are some ideas which have been suggested to explain why the Moon has different phases.

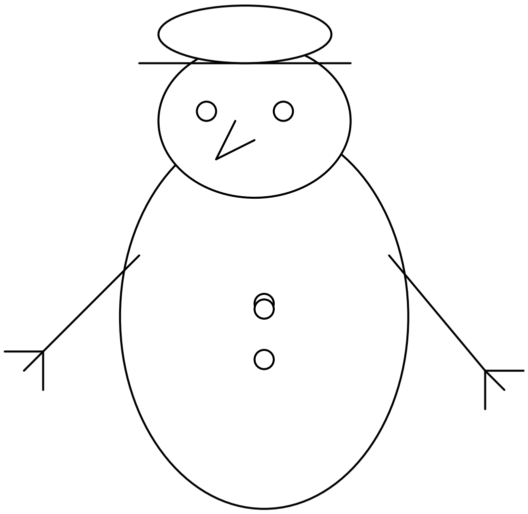
- Read the explanations carefully and discuss them in your group.
- Choose the best explanation and give your reasons why you decided this was the best.
- Then try to give reasons why you think the other explanations are not so good or are wrong.

A	The Moon spins around so that the half of the moon that gives out light is not always facing us
B	The Moon shrinks and then gets bigger during each month
C	The rest of the Moon is blocked out by clouds
D	We cannot always see all the part of the Moon which is lit up by the sun
E	The Moon moves in and out of the Earth’s shadow and so light from the sun cannot always reach the Moon

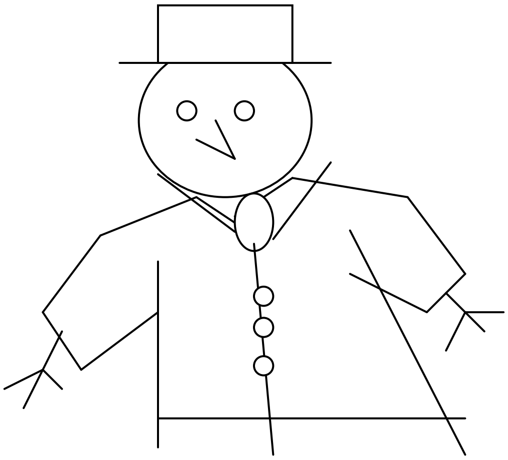
Appendix 5

The Melting Snowmen?

Fred



Birt



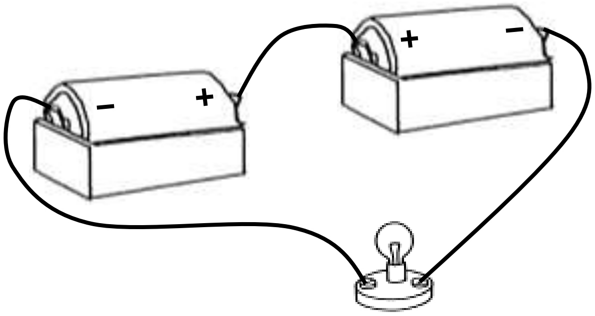
I think that I will melt first because the sun will hit me and the heat energy will change my snow into water

I think I will melt first because I will trap all the sun's energy inside my coat and this will cause my snow to melt into water

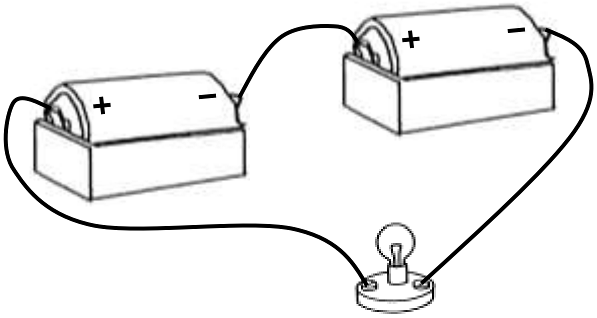
1. Which snowman do you think will melt first?
2. Why have you decided this?
3. Do you agree with the science behind Birt's argument?
4. Why?
5. Using the pieces of evidence given to you try to rewrite Fred's argument on the next diagram so that it is more convincing. (Be careful. Not all information is necessarily useful!)

Appendix 6

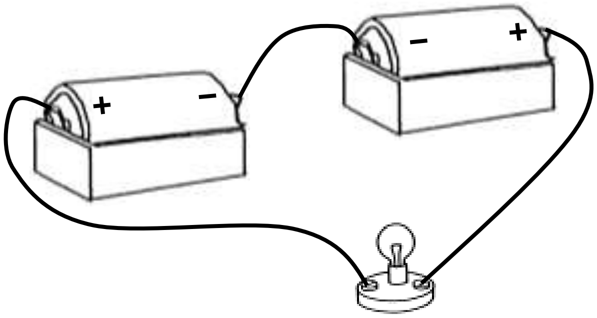
The bulbs in these circuits are the same. The batteries are also all the same, but they are not connected the same way round in each circuit.



a.



b.



c.