Commentary: Fostering Students' Argumentation Skills in Geoscience Education

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ABSTRACT

This paper considers opportunities for teachers to use an argumentation pedagogy in order to develop students' geoscience thinking skills. Educational argumentation principles and procedures are outlined. Argumentation can foster both student and teacher motivation and interest in the context of accessible and well-structured geoscience content. Geoscience lends itself to an argumentation approach because of its physical and intellectual accessibility, its concern with 'socio-scientific' ideas, its operation on scales readily understood by children and its regular occurrence in mass media reports. Students need to learn how to construct an argument, supported by evidence, and to learn from counter-arguments. Argumentation involves both cognitive and affective skills of both teachers and students. It can be used to help children understand not merely the socio-cultural aspects of science but also basic science concepts and processes. A geosciences argumentation pedagogy is exemplified using coastal evolution: argumentation procedures and protocols are illustrated and explained. Four other potential opportunities in geoscience education are summarised in tabular form. The paper concludes by emphasising the critical role of epistemological understanding: it cannot be ignored.

INTRODUCTION: CHANGING PRIORITIES IN GEOSCIENCE AND SCIENCE TEACHING

Science education seems to be in constant crisis, at least in UK schools, as indicated by student enrolments in post-16 science courses (it is mandatory to 16 years) and students' declared interests, priorities and career objectives (Trend, 2009a). Potential remedies lie both within and beyond science education (Butroyd, 2008) and include the focus of this paper: argumentation pedagogy. In contrast, school subjects within the social sciences and humanities are thriving: notably psychology, philosophy, economics, history, citizenship and religious education. All are subjects which routinely involve debate, controversy and argumentation. The perception of science as a cold, controversial, divisive and potentially anti-social activity persists among students, summarised by Ramsden (1998) as: "the widely held perception of science being difficult and not relevant to the lives of most people; of science causing social and environmental problems; that science is more attractive to males than females; that interest in science decreases over the years of secondary schooling; that these more negative views are associated with the physical sciences rather than the biological sciences" (p.125).

Given the unsatisfactory position of science in schools, including geoscience, what steps can be taken to improve matters? Many: we are not short of answers to this question. Several of them involve the use of argumentation in teaching, a widely researched approach for fostering learning among school students (Gott and Duggan, 2007) and their teachers (Simon and Johnson, 2008). In recent years this has become a growth area in science education research (Coffin and O'Halloran, 2008), with an increasing number of studies across the sciences (Cross et al., 2008). Here I examine some specific issues that arise in relation to geoscience and argumentation.

The UK curriculum changes introduced from September 2006 represent a distinct loosening of control by government, with schools being given wider choice of curriculum content and breadth, although science remains a compulsory subject for all students to the age of 16 years. Current developments also include (i) the systematic inclusion of thinking skills (Adey and Shayer, 1994; Taber, 2008), (ii) a higher profile for science in society (SIS) issues, notably linked to the mandatory subject of Citizenship (Jenkins, 1999, 2006) and (iii) increased attention to developing scientific literacy, a label first used systematically in the 1950s (Hurd, 1958) and now used increasingly in relation to the aims of new science curricula (Hurd, 1998) on a global scale (Millar, 2006).

Built on a major research-based report (Millar and Osborne, 1998), "Twenty First Century Science" is an innovative and very flexible UK science curriculum for 15- and 16-year-old students designed explicitly to enhance scientific literacy (Millar, 2006). Structured explicitly around biology, chemistry and physics, it provides a 2-year course for all students, including those likely to study science to an advanced level ("science for all and science for scientists"). In relation to curriculum content, the authors of the programme decided that "what citizens require is a broad, qualitative grasp of the major science explanations; the detail which many students find off-putting is rarely needed" (Millar, 2006, p. 1507). Such content was expressed as sixteen "core explanations", several of which are predominantly geoscientific (eg "The structure and evolution of the Earth" and "The theory of evolution by natural selection") and most of which have geoscience connections (eg "Energy sources and use" and "Materials and their properties"). More important for geosciences educationalists than any detailed content is the rationale offered for the composition of this list: "the primary selection criterion [for content] was that an explanation should be included only if an understanding of it might make a difference to a decision or choice that a citizen could have to make, or to the viewpoint he/she might hold on an issue or decision at local or national level, or if it offered a culturally significant view on the human condition (on our ideas about 'who we are and where we are'). The latter, for example, justifies the inclusion of ideas about human evolution and cosmology

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which have less obvious practical implications" (p. 1507). Such a rationale has immediate implications for teachers since such aims are unlikely to be met through traditional didactic approaches: a participatory pedagogy is required. Argumentation meets this requirement.

WHAT IS ARGUMENTATION?

Science is a socio-cultural activity: people engage in scientific endeavour collectively and that collective activity contributes towards that nation's cultural identity. Any nation's schools have a duty to develop scientific literacy among its pupils so that they can participate in democratic debate on scientific matters of significance. Citizens also need the skills to discuss the nature and purpose of science, skills that can be developed in school. Argumentation is the antidote to archaic perceptions of science, which still persist in some UK schools (Driver et al., 2000), as a tightly positivist, fact-ridden, unimaginative and formulaic set of procedures, largely divorced from emotion and certainly moving away from the errors of past science activity. Argumentation accepts that people engage in dialogue as part of their science work in order to advance knowledge and understanding. It represents a powerful tool for developing children's science learning, especially their higher order cognitive skills of understanding, application, analysis, synthesis and evaluation (Osborne et al., 2006; von Aufschnaiter et al., 2008). In this paper I suggest several ways in which argumentation can be used in the context of geoscience teaching and learning.

Argumentation, as I am treating it here, is a form (or genre) of human discourse which: (i) is rational; (ii) has several distinctive components; (iii) involves both intellect and emotion (affect), and; (iv) is designed to resolve or advance an initial claim or opinion through persuasion based on evidence. The term 'argumentation' refers to the process whereas the term 'argument' refers to the initial proposition and its subsequent debate: the 'content' around which the process of argumentation takes place. Mason and Scirica (2006) provide a pithy and well-referenced account of argumentation skills in the context of classroom-based teaching and learning. 'Argumentation' and 'debate' are not quite synonymous since the first implies the systematic implementation of agreed procedures (and labels), whereas 'debate' has a great diversity of meanings and connotations because it refers to any form of structured discourse.

It is only in the last few decades that argumentation has entered science classrooms in a structured and formal way, notably as part of the desire to focus on children's scientific literacy (Gott and Duggan, 2007) and wider thinking skills. It is part of the shift towards a more explicit recognition that scientific knowledge is socially constructed by learners and that structured discourse leads to enhance conceptual learning. Indeed, Kuhn (1993) argues that it is the argumentation process which most closely corresponds to the thought processes in science, claiming that "we can find scientific thinking in older children, adolescents, and lay adults if we conceive of it as argument" (p.322). She concludes that "science as exploration and science as argument do not in fact contradict one another" and that "the natural curiosity that infants and children show about the world around them needs to be enriched and directed by the tools of scientific thought" (p. 335). This constitutes the underpinning rationale for the current paper.

Argumentation also has the potential to improve students' attitudes towards science, their enjoyment of science learning and their powers of reasoning. Thorough descriptions and analyses of the role argumentation in science and in science education are given elsewhere (Cross et al., 2008; Driver et al., 2000; Duschl and Osborne, 2002; Maloney and Simon, 2006; Mason and Scirica, 2006; Sadler and Donnelly, 2006; von Aufschnaiter et al., 2008). The following is a brief summary of these ideas, with some illustration with geoscience concepts.

Stephen Toulmin's classic book (Toulmin, 1958) marked the start of the modern interest in argumentation as a process of reasoning between two or more people which incorporates both cognitive and affective skills. He had a special focus on legal discourse. Since then, other authors have presented his approach as a model comprising four core elements, labelled 'data', 'claim', 'warrant' and 'backing' and many authors have refined the model beyond these elements, especially researchers seeking to develop and evaluate new ways of implementing an argumentation pedagogy. As the opening stage in an argumentation process, a 'claim' (proposition) is made by reference to 'data' (information). This might be something such as 'the continents of Africa and South America were once united [claim] because identical fossils and rock types can be found on matching coasts and hinterlands [data]'. A third element comprises a 'warrant', which gives the link between the data and the claim: the reason WHY the claim arises from the data. In this example two relevant warrants might be 'organisms that can only survive in shallow seas cannot cross the deep Atlantic Ocean' and 'identical fossil species are almost always of the same geological age'. A fourth key element is called the 'backing', which comprises the agreed basic assumptions in the system: here they would include organic evolution, preservation of fossils and the formation of sedimentary rocks, but they would not include plate tectonics (or drifting continents) since that forms the central claim. In addition to the four central elements identified above, we can recognise 'rebuttals' and 'qualifiers'. A rebuttal is a challenge to the claim (a counter-claim), with supporting evidence. In other words, a counter-position is taken up and appropriate evidence is cited. A rebuttal in our continents example would be the claim that landbridges and shallow seaways existed between Africa and South America and that the continents have not moved in relation to each other. Evidence would include the various mid-Atlantic islands such as Canaries, Cape Verde, Falklands, Tristan da Cunha and St Helena. A 'qualifier' is a refinement of the original claim: a statement of the conditions under which the claim is true. In our drifting continents example, a qualifier might refer to variation in possible speeds of continent separation (eg between 2 and 5 cm. pa) and, therefore, possible dates for initial rifting.

A few more concepts (and their name labels) can help in the analysis of argumentation. When claims (or propositions) are made, it is important for children to be able to distinguish between the following basic scientific concepts: 'facts' (universally agreed propositions), 'assertions', 'hypotheses' and 'theories'. During argumentation, children draw on 'evidence' to support a claim, rebuttal or a qualifier: this evidence may be 'personal' or 'authoritative'. They also adopt strategies which may be designed to cause or accentuate either 'conflict' or 'collaboration', which in turn might lead either to an agreement to differ ('coexistence') or to a 'consensus'. Strategies may be cognitive (eg elaborating or clarifying an explanation) or they may be social (eg body language to signify disapproval). Furthermore, they might seek allegiances with others to enrich their claim or rebuttal through cognitive or social means; or they might seek to act alone.

Finally, some authors (Kim and Song, 2006) have recognised 4 stages in the argumentation process, at least in the context of science experimentation: (i) an initial 'focus' when the ground is prepared; (ii) a second 'exchange' period when ideas are discussed in order to agree the way forward; (iii) a third 'debating' stage when the claims are actually discussed, and; (iv) a final 'closing' stage, which may be explicit, implicit or circumstantial, reflecting declining levels of final agreement.

THE ROLES OF INTEREST, MOTIVATION AND PRIOR KNOWLEDGE

If argumentation is to be used in the classroom to foster geoscience learning, the inter-related issues of interest (Trend, 2009b) and prior knowledge and understanding must be addressed carefully (Mason and Scirica, 2006; Sadler and Donnelly, 2006), for both students and teachers. First, in relation to students' geoscience interests, it as been shown that academic attainment is more closely related to 'individual interest' (the robust, stable, long-lasting form of interest, developed over some time) than to 'situational interest' (the transient, temporary, short-lived for of interest typically generated by teachers in classrooms) (Hidi and Renninger, 2006). Second, in relation to students' prior knowledge, there is nothing worse for classroom discourse than ill-informed dialogue that degenerates into vague generalisation, prejudiced assertion, personal attack and all-round disaffection. In our 'drifting continents' example, students' prior knowledge and understanding of plate tectonics and palaeogeographical principles and theories would seem to be pre-requisites. However, some research shows no correlation between the quality of students' argumentation and their prior knowledge of the topic in question, beyond a basic level (Means and Voss, 1996). Although it appears to be counter-intuitive, "we cannot assume that increases in content knowledge necessarily improves the quality of argumentation" (Sadler and Donnelly, 2006,p. 1485). It seems likely that a threshold effect is present: a minimum level of knowledge and understanding of the content is necessary, but beyond that there is no relationship between students' prior knowledge and their argumentation quality. This assertion raises many research questions which cannot be addressed here, such as: what is the minimum level of knowledge required for effective argumentation; how can teachers determine that minimum level for any given curricular context; how does this basic geoscience knowledge level vary between students (do some need to know more than others to participate well?); which facets of geosciences cognition are enhanced through argumentation (knowledge, comprehension, evaluation, analysis, synthesis)? The problem of the required knowledge-content threshold for effective argumentation is critically important yet impossible to address systematically since it varies for each student and the topic being studied. The solution lies with the craft skills of the teacher: knowing how much contextual knowledge is essential for each stage in the argumentation procedure and for each student.

When it comes to implementing an argumentation pedagogy in the geosciences classroom, issues of motivation, confidence and geoscience subject knowledge and interest (Trend, 2009a, b) relate to teachers as much as to their students. In particular, teachers need to be supported in the school workplace through the provision of the three basic psychological needs of autonomy, competence and social relatedness (Ryan and Deci, 2000; Vansteenkiste et al., 2006). Like their students, teachers are learners who flourish when these three ingredients have their impact, so school managers and leaders, fellow teachers, education academics and others have a role to play in supporting teachers as they develop new pedagogies.

First, briefly, the need for teacher autonomy implies a professional freedom to make informed judgements concerning their students' learning needs. An argumentation approach is unlikely to succeed if the teacher is a reluctant participant. Second, teachers must have the resources (time, equipment, accommodation….) and possess the professional knowledge and understanding which enables them to bring argumentation to their classroom. Feelings of competence are insufficient: teachers must be competent. Finally, the pedagogical approach needs to stimulate the teacher's feelings of relevance and relatedness to the wider social context, notably the body of teachers and educators within and beyond the school. These comprise the source of each teacher's sense of professional purpose. The acknowledgement and addressing of these three categories of psychological need will narrow the gap between esoteric rhetoric and classroom practice. This issue is further addressed below in the context of a three-level hierarchy of epistemological understanding.

THE ROLE OF STUDENTS' AND TEACHERS' EPISTEMOLOGICAL UNDERSTANDING

Several factors are known to inhibit argumentation, including: well-developed personal belief systems; a level of topic knowledge and understanding which is below some (usually unspecified) threshold; a psychological disposition towards maintaining warm personal relationships; a lack of willingness to learn from argumentation; lack of opportunities provided by the teacher, and; a low level of epistemological understanding. On this last point, recent empirical research into the ontogenetic changes in epistemological understanding indicates a progression through several stages from an absolutist to an evaluativist approach, although there are many variants of this scheme. This work builds on the pioneer writings of William Perry (1970), based largely on ontogenetic cognitive development among university students. Hofer and Pintrich (1997) provide a substantial critical review of these research programs. Recent empirical work shows that the learning process itself evolves with human growth, notably in relation to epistemological understanding (Kuhn et al., 2000), but such changes vary enormously between individuals and some results "suggest that some 12-year-olds have become as capable as many adults in managing the interaction of theory and evidence in their own thinking, in a way that supports effective learning" (Kuhn and Pease, 2006, p.293). This range of competences among students clearly has direct implications for teachers' management of classroom activities on argumentation.

In their empirical study involving 62 children aged 13 years, Mason and Scirica (2006) relate a three-level hierarchy of epistemological understanding to argumentation pedagogy in the context of global warming and genetically-modified food. Their hierarchy comprises the categories of: (i) absolutist, (ii) multiplist, and (iii) evaluativist. Most children function within the first stage, so they "believe that knowledge is absolute, certain, non-problematic, right and wrong, and does not need to be justified since observations of reality or authorities are its sources" (p.494). Such a stance clearly has serious implications for geoscience educators and their students' perceptions of authority, not least in relation to matters of deep time, evolution and young Earth creationism. Compare, for example, the learning potential of a student who accepts the age of the Earth (or evolutionary change) as given by (any) authority and that of a student who adopts a questioning stance towards such assertions.

By adolescence, most people's epistemological understanding has advanced to the "multiplist" level, so they tend to "believe that knowledge is ambiguous, idiosyncratic, and each individual has his or her own views and truths" (p. 494). Many adults (including perhaps most teachers) attain the "evaluativist" level, when they "have an epistemology grounded on the belief that there are shared norms of inquiry and knowing. Thus, some positions are reasonably more justified and sustainable than others" (p. 494). Although it has been suggested that "adults of all backgrounds are highly likely to make the transition from absolutism to the multiplist acceptance that knowledge is uncertain and divergent claims legitimate", (Kuhn et al., 2000, p.324), the same authors report that "no more than half of adults of any background and in any judgment domain make the subsequent transition to the evaluativist position" (p.324). This should give us cause for concern because it suggests that some teachers possess a more sophisticated epistemology than others, permitting them to guide their students in more powerful and effective ways as they engage in argumentation.

Oral communication is at the heart of argumentation, so it is important for teachers to interpret student utterances. Some students' expressed thoughts may reflect their stable and secure understanding of the concept or phenomenon whereas other expressed thoughts may be transient, unstable, and tentative for which the student has no commitment (Taber, 2008). In other words, teachers need to understand their students' communications as they use them to diagnose learning. Of course, in most cases a progressive refinement of student understanding occurs alongside the child's development of oral language and growing confidence.

The level of epistemological understanding has several implications for teachers when they devise learning activities involving argumentation. First, classroom argumentation involving young children is likely to focus on agreed knowledge derived from authority: any attempts to challenge such authorities may cloud the discourse and inhibit argumentation. In other words, there needs to be acceptance that the child functions at the 'absolutist' level. Second, students functioning on a 'multiplist' level (ie middle-level) are more likely to accept the existence of different viewpoints and to recognize contradictory interpretations of evidence than are the 'absolutists': this can enhance the quality of argumentation. Third, although the three levels have been cited as age-related, some regard them more as dispositions than intellectual competences. This means that teachers are likely to find both 'absolutists' and 'multiplists' in their class, and perhaps even some 'evaluativists' who will respond most favorably to any outcome of argumentation!

GEOSCIENCE AND ARGUMENTATION

Geoscience lends itself to argumentation approaches to pedagogy for several reasons. First, many geoscience topics can be labelled as 'socio-scientific' which lend themselves to learning through argumentation (Sadler and Donnelly, 2006). Global warming and natural hazards are good examples. Second, geoscience materials are readily accessible, both physically and intellectually: rocks, fossils, oceans, landscapes, minerals and so forth. Third, much geoscience operates on scales which are readily understood by children, typically measured from centimetres to hundreds of kilometres, rather than the micro-scales of nano-science and the macroscales of astronomy. Indeed, it has been reported that "the main indicator of whether or not a high quality of argument is likely to be attained is students' familiarity and understanding of the content of the task" (von Aufschnaiter et al., 2008, p.101). Fourth, geoscience issues are often reported by mass media, so children are familiar with many of the concepts or, at least, their name labels.

Although there have been many reports and theoretical discussions on the development of thinking skills in geoscience classrooms (Assaraf and Orion, 2005; Orion and Kali, 2005; Rankey, 2003), little research has been published about the systematic use of argumentation in geoscience teaching and learning. There are of notable exceptions (eg. Clayton and Gautier, 2005) and many of the argumentation examples used in the wider science education literature include familiar geoscientific phenomena such as global warming (eg. Mason and Scirica, 2006). Geoscience also figures in studies of students' writing skills (Yates et al., 2005). Here I want to examine ways in which students can engage in structured and systematic argumentation around judiciously identified geoscience topics, with a further benefit being a more secure grasp of that epitome of a geosciences threshold concept (Meyer and Land, 2006): deep time. To that end, one example is developed in some detail (coastal processes) and five further examples are summarised in tabular form.

In the following discussion the educational emphasis is on the science itself, in contrast to the oft-stated perception that it is the socio-economic implications and consequences of the science that best lend themselves to an argumentation approach. As a result of this widely-held view, much educational research and practice in this field tends to emphasise the socio-economic aspects of science because these are perceived as lending themselves to the development of contrasting opinions more readily than is the science itself. For some teachers this is true: they find it easier to devise learning activities which bring out the political, socio-economic and cultural aspects of science, rather than the science 'per se'. This view has to be challenged since science is often a social activity, involving argument derived from scientific evidence. The contrasting positions adopted by scientists are not simply 'opinions' in the colloquial sense, based on their world views or belief systems; they are positions which arise from their professional judgements made after considering the evidence (albeit influenced by their values, attitudes and belief systems). The problem for teachers, however, comes when the children have 'absolutist' views of science (Mason and Scirica, 2006): they are unable (or find it difficult) to engage with opposing viewpoints and see no need to justify any claims. Perhaps argumentation provides an opportunity for teachers to develop pupils' skills in metacognition so they move closer to a 'multiplist' position. Accordingly, in the following discussion, a central aim is to identify contrasting scientific viewpoints, rather than opinions, which can be defended or challenged with reference to evidence obtained from the world external to the student.

EXAMPLE IN DETAIL: COASTAL PROCESSES AROUND BAYS AND HEADLANDS

This detailed exemplification of argumentation is based on the idea that many coastal features, notably bays and intervening headlands, can only be understood with reference to sea level change through deep time: two key variables that are typically omitted from UK school texts and websites.

Children often encounter the idea that coastal bays are formed by the marine wave erosion of 'soft rocks' and that headlands result from 'tough rocks' which resist such wave erosion. Bays arise directly from marine erosion. Such descriptions and explanations are common in UK textbooks and related websites. However, it is easy to demonstrate to students that extant processes operating in such environments usually show maximum erosion on the headlands, in a high energy environment, and maximum deposition within the bay, typically marked by a large bay-head beach. In other words, there appears to be a contradiction between commonly held ideas and the field evidence. Such a contradiction is easily presented to students. And it is this property which renders this topic ideal for an argumentation pedagogy. It is particularly effective when the various ideas are introduced to students in the field on a stormy day! The apparent contradiction provides the stimulus and starting point for the argumentation process.

One possible approach is to foster children's argumentation using the 'competing theories' approach. First the apparent contradiction is presented, as above, to stimulate thought and informal discussion, ideally before, during and after a field visit. According to student ages and abilities, the teacher then stimulates hypotheses or prompts students to suggest possible theories to explain the phenomena. Claims can then be offered at this initial stage, with supporting evidence, again ideally in the field. These opening claims might lead to counter-claims and thence continued dialogue (debate) back in the classroom. In short, the competing theories are generated by the students by drawing on their previous learning and, inevitably, much depends on the management of this classroom discussion.

Alternatively, several possible theories (three in this case) can be presented to students directly as resource cards: see Fig. 1. Students can be arranged into small groups or pairs to examine and defend each theory. Whatever the source of the theories (student or teacher or both), they can be analysed and evaluated as appropriate. The text should be analysed and, for example, facts, assertions and theories should be distinguished from each other. Once the several competing theories have been studied and perhaps summarised, the students need to engage with potential evidence which may be obtained from field activities or it may be presented by the teacher, or a combination of both. The teacher may introduce items of evidence as another set of cards: see Fig. 2. Each of these can be introduced at strategic times during the discussion: a drip-feed approach. Such evidence cards would then have to be sorted by students as either (i) 'potential evidence in favour of a theory', (ii) 'potential evidence against a theory' or (iii) 'potentially irrelevant'. In addition to the evidence cards, or possibly replacing them, further evidence can be called upon by students to develop their case, typically from the Internet or from field observations.

Further resources can be introduced to enrich the debate and provide for qualifiers to be identified. For example, a map sequence to show the geomorphological evolution of the relevant stretch of coastline over time can be presented, with the added ingredient of a sorting task to place the maps in their correct sequence.

The range of epistemological understanding among students impacts on the nature of this coastline discourse, but not necessarily on its quality, and one of the key purposes of this pedagogy is to enhance such student understanding. The teacher should identify students

THREE POSSIBLE THEORIES OF BAY FORMATION
Theory One The bay is currently being eroded faster than the headlands. The powerful waves create the bay by eroding the land through the sediment: the sediment is moved around and that then erodes the land. Although wave erosion appears greatest on the headlands, the rock strength and toughness prevents much erosion, so they remain as headlands. Also, the land is higher at the headlands so there is a greater volume of rock to be eroded.
Theory Two The headlands are currently being eroded faster than the bay so eventually the coastline will be straight. The bay was formed by direct wave erosion in the past but this has now stopped because the bay itself is giving protection against further wave erosion. Wave refraction causes dissipation of the energy within the bay, so deposition is occurring now.
Theory Three The bay was first formed when sea level rose at the end of the Ice Age (global ice melting), flooding the lower land which had previously been a river valley. The wave action has made the bay gently curved by moving sandy sediment into it. The headlands are now being eroded faster than the bay which is actually being filled in, so eventually the coastline will be straightened. A further sea-level rise in the future would disrupt the tendency towards a straight coastline by flooding low-lying land.

FIGURE 1.

EVIDENCE CARDS

- Sand adjacent to the low cliff in the middle of the bay is rarely moved by breaking waves.
- Wave refraction causes wave energy to become concentrated at the headlands but dissipated within the bay (refraction).
- The land behind the bay is at a lower altitude than the land behind the headland.
- A nearby inlet has been cut off from the sea by a bar and has now silted up completely.
- The rock type is the same throughout the whole region: a thick, hard, tough sandstone at both the bay and headlands.
- The bay is very shallow, with much sand on the bottom.
- A river enters the sea in the middle of the bay.
- About 200 metres inland there are the remnants of a raised beach, about 15 metres above presentday sea level.

FIGURE 2. Evidence Cards

AN APPROACH TO ARGUMENTATION TO TEACH COASTAL EVOLUTION THROUGH POST-GLACIAL TIME

Here the idea is to set up a sequence of (say 6 to 8) coastline maps at different evolutionary stages to show an evolving coastline which can be explained by bringing in the temporal variable, especially post-glacial sea level rise (of about 100 metres). Other (i.e. static) theories are possible

- The final map is the present-day one.
- The first map shows a highly indented coastline following the post-glacial sea-level rise (known as the Flandrian Transgression: up to c6,000 years BP).
- Each map shows recognisable coastal features: cliffs, beaches, bays, headlands, etc. as they evolve over the last 6000 years.
- Discussion centres on the possible sequence of events and possible explanations.
- Could be based on a local/real/studied area.
- Product could be class presentation with questions, Powerpoint etc.
- Could be expanded to include sustainable management of the coast over the next 20 years: soft and hard solutions, reconciling conflicting interests etc. What time durations do we mean in relation to "sustainable" and what can the deep past show us?
- Could be expanded to include prediction: what will the coastline be like in another 1,000 years if sea level were to rise steadily by 100 metres? Explain and justify to rest of class.

FIGURE 3.

starting from an 'absolutist' position and take care to guide them towards a consideration of evidence which suggests alternative theories, thereby assisting their passage to a multiplist position. . Similarly, 'multiplist' students should be encouraged to evaluate the range of theories, perhaps ranking them in order of efficacy (an 'evaluativist' stance).

Other approaches to encourage learning through argumentation over this sea-level change example can be developed. For example, the map sequence mentioned above can form the main item of evidence, with the main challenge being to explain how the present day coastline has evolved: see Fig 3 for an example of this approach. The two most important points in both approaches are that (i) students use structured argumentation to engage in real debate over possible explanations for coastal evolution and (ii) the deep time perspective is added to the equation: it is often ignored. A third issue which can be included relates to the argumentation process itself: students can be taught the techniques, labels, concepts and protocols of argumentation in order to reflect on their own learning and thereby improve the quality of their argumentation skills. Such an approach has been shown to enhance learning (von Aufschnaiter et al., 2008).

The extent to which argumentation can result in enhanced geoscience knowledge and understanding depends not only on the quality of the arguments (contents) but on the social interaction between participants; so the classroom climate is critical. Ideally, claims based on observations and deduction are challenged or supported with reference to wider lines of evidence, eventually coming to include the full range of

OVERVIEW	DISTINCTIVE OR EXEMPLAR ELEMENTS
Example 1: Drifting Continents	
Classical geological claims and counter-claims for ‘drifting continents’ lend themselves to argumentation. Lines of evidence include: matching coastlines; matching lithologies; matching fossils; matching orogenic belts; lack of agreed motive force; and so forth. These can be presented in the form of evidence cards.	***Claim:*** ‘India has migrated northwards and collided with Asia to create the Himalaya Mountains and Tibetan Plateau’. Evidence: may be supported by a wide range of evidence familiar to all geologists. ***Warrants:*** include the consensus science that evidence of linear mountain chains result from continental collision. ***Backing:*** distribution of recent earthquake activity andpalaeogeographical evidence linking India with east Africa and Antarctica. ***Qualifiers:*** relating the collision to a deep timescale. ***Challenges (rebuttals):*** bring in discussion of land bridges, parallel evolution and submerged cities. ***Data:*** The Deccan Plateau - why is it there and can it be linked to a mantle plume?
Example 2: Plate tectonics and hot spots	
The issues are similar to Example 1, with widely-known concepts relating to plate tectonics (PT). The PT model can stimulate argument concerning: climate change; sea-floor spreading; mid-oceanic ridges; orogenic belts; intra-plate volcanism; and so forth. The model has implications at all scales, from global and continental to local and regional. Teachers can make links between local geology (lithologies, structures, fossils, tectonic activity, etc.) and plate tectonics. Mantle plumes provide a first rate entry point for students in their study of plate tectonics. Mantle plumes are well-known, yet are persistently scientifically controversial. Various explanatory theories can be readily explored.	***Hypothesis testing.*** Students predict, retrodict and test hypotheses against readily-accessible evidence, at least using secondary sources. ***Conflicting theories.*** Teachers represent conflicting scientific positions with reference to specific items of evidence. For example, the global distribution of recent seismic activity can stimulate students to generate hypotheses concerning plate behaviour in both intraplate and inter-plate contexts. ***Evidence for motive forces.*** Possible motive forces and mantle behaviour addressed in terms of tension (linked to subduction), compression (linked to MOR spreading), whole-mantle convection, lower-mantle convection, plumes and hot-spots, and the asthenosphere. Various kinds of evidence invoked to support claims or rebuttals (eg large-scale tension structures to support slab-pull). ***Claims and rebuttals.*** Claims and rebuttals should refer to plate movement, mantle behaviour, intraplate forces, migration of plume activity, geochemistry of hot spot magmas, dating of Pacific Plate rocks adjacent to Hawaii-Emperor chain, vertical rates of plume movement and so forth.
Example 3: Mass Extinctions	
One ingredient often missing from work on biodiversity and biological extinction is the deep timescale: hence the topic of mass extinctions through geological time. The nature, timing, distribution, causes and consequences of mass extinctions provide ideal contexts for argumentation discourse and provide a simple route into systems thinking by showing how changes in one system (eg cryosphere or geosphere) can have cumulative consequences for other systems (eg biosphere and atmosphere).	***Background knowledge.*** Standard devices used for basic background information: reading; card sorting; internet/library searching; sharing; pooling; presenting, and; the study of palaeogeographical reconstructions. ***Claims.*** These might relate to primary causes, with evidence covering fossil counts linked to specific lithologies within rocks of known ages. ***Warrants.*** Some warrants expected to cite lithologies reflecting depositional environments and fossils as evidence of past life. ***Rebuttals.*** These might refer to imperfections in the fossil record or contrasts between marine and terrestrial environments. More sophisticated rebuttals might include discussion of taxonomy. ***Qualifiers.*** These might address the temporal occurrence of mass extinctions, with reference to the ‘big five’, the possibilities of a 26 my cycle and to prevailing palaeogeographies. ***Assessment.*** Argumentation quality to be assessed against many criteria, including selection and presentation of appropriate evidence. **EXAMPLE 1**: the different types of evidence indicating a K/T bolide impact would have to allow for a palaeogeographical reconstruction of continents at 65 MA.

	EXAMPLE 2: argument for mass extinction impacting solely on marine organisms may not be explained satisfactorily by sudden climatic change. References to the current mass extinction would provide strong temporal links with Earth's deep history and modern events, including the recently-recognised (?)extinction of the white-fin dolphin from the Yangtze River.
Example 4: Snowball Earth	
Snowball Earth hypotheses are fundamentally integrative, drawing on evidence which requires interpretation and student engagement with diverse global processes and concepts of both Neoproterozoic and the present day, including: • organic evolution; • atmospheric evolution; • Rodinia fragmentation, plate tectonics and changing palaeolatitudes; • glaciation; • glacial deposits and ice transport mechanisms; • lithification; • changes in ocean water chemistry and circulation; • the relationships between atmospheric oxygen and banded iron formation (BIF); • links between climate change and silicate weathering. In short, the topic itself can be a gateway to wider geoscience learning.	Snowball Earth (SE) possesses attributes which make it appropriate for argument-based learning: ***Interest.*** The topic captures students' initial interest ("Triggered Situational Interest") and provides opportunities for learners to move to more sustained situational interest and then develop even more robust levels of individual interest (Hidi and Renninger, 2006). ***Current research.*** The main scientific activity has occurred within recent decades, so making it more accessible to young people. Paul Hoffman and Joseph Kirschvink are active workers, giving an immediacy for the concepts (Brian Harland, another pivotal worker, died in 2003). ***Alternative theories.*** These explain the evidence of low-latitude glaciation cycles, including large variation in angle of tilt of Earth's rotational axis and even the suggestion of periodic ice storms descending into the atmosphere. Further theories can be offered to explain the evidence, including ice rafting and flood deposition. ***Present and past.*** SE links the familiar Quaternary glaciation with similar conditions in Earth's deep past, fostering children's own Deep Time Framework of pivotal geo-events (Trend, 2001). ***Differentiation.*** Argumentation about SE works at almost any intellectual level (and student age and ability). At the basic level children develop claims and counter-claims linking glacial sediment with changing palaegeographies and rapid ice melting by geothermal heat. At a higher level students focus on palaeomagnetic evidence and the complexities of ice/ocean albedo contrasts.

FIGURE 4.

past and present variables known to be impacting on coastlines. In this example, coastline evolution through deep time should be included as the critical explanatory factor, rather than excluded as being irrelevant to the development of bays and headlands.

FOUR EXAMPLES IN OUTLINE

Some geoscience topics lend themselves to an argumentation pedagogy more readily than do others. The four examples summarised in Fig. 4 have been selected because they possess contrasting features which permit this approach. In each case the summary gives brief pointers based on classic argumentation elements.

CONCLUSIONS

Geoscience appears to be in a strong position to further the development of classroom argumentation strategies because it includes so many concepts and processes that have high profiles in political, educational and socio-cultural debates. The science behind critical and familiar processes such as climate change, seismic activity, coastal and river flooding and potential asteroid impact needs to be taught in the classroom in ways which stimulate and motivate children. Argumentation has the potential to meet that imperative. However, interest, motivation and attitudes towards knowledge cannot be ignored. The pivotal issue of epistemological understanding needs careful attention if this approach is to pay learning dividends since each child perceives knowledge, and its source and authority, in their own distinctive way. Teachers need to be aware that such diversity in perception leads to contrasting attitudes towards matters such as knowledge, argument, evidence, theory and proof. The categories of absolutist, multiplist and evaluativist provide teachers with a logical and structured framework in which to address such diversity in the classroom, giving them opportunities to apply their craft skills and their professional knowledge of their own students in developing an effective argumentation pedagogy.

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REFERENCES

Adey, P., and Shayer, M., 1994, Really Raising Standards: cognitive intervention and academic achievement: London, Routledge.

Assaraf, O., and Orion, N., 2005, Development of system thinking skills in the context of earth system education: Journal of Research in Science Teaching, v. 42, p. 518-560.

Butroyd, R., 2008, Schooling and subject disengagement in Year 10 Science in four maintained schools in northern England: Research in Education, p. 22-37.

Clayton, D.S., and Gautier, C., 2005, Scientific argumentation in Earth system science education: Journal of Geoscience

Education, v. 54, p. 374-382.
Coffin, C., and O'Halloran, K., 2008, Researching argumentation in educational contexts: new directions, new methods (special issue, editorial): International Journal of Research & Method in Education, v. 31, p. 219-227.
Cross, D., Taasoobshirazib, G., Hendricksc, S., and Hickeya, D.T., 2008, Argumentation: a strategy for improving achievement and revealing scientific identities: International Journal of Science Education, v. 30, p. 837.
Driver, R., Newton, P., and Osborne, J., 2000, Establishing the norms of scientific argumentation in classrooms: Science Education, v. 84, p. 287-312.
Duschl, R.A., and Osborne, J., 2002, Supporting and promoting argumentation discourse in science education: Studies in Science Education, v. 38, p. 39-72.
Gott, R., and Duggan, S., 2007, A framework for practical work in science and scientific literacy through argumentation: Research in science & technological education, v. 25, p. 271.
Hidi, S., and Renninger, K.A., 2006, The four-phase model of interest development: Educational Psychologist, v. 41, p. 111 -127.
Hofer, B., and Pintrich, P., 1997, The development of epistemological theories: beliefs about knowledge and knowing and their relation to learning: Review of Educational Research, v. 67, p. 88-140.
Hurd, P.D., 1958, Science literacy: Its meaning for American schools: Educational Leadership, v. 16, p. 13-16.
—, 1998, Scientific literacy: New minds for a changing world: Science Education, v. 82, p. 407-416.
Jenkins, E.W., 1999, School science, citizenship and the public understanding of science: International Journal of Science Education, v. 21, p. 703-710.
—, 2006, School science and citizenship: retrospect and prospect: School Science Review, v. 88, p. 113-118.
Kim, H., and Song, J., 2006, The features of peer argumentation in middle school students' scientific inquiry: Research in Science Education, v. 36, p. 211-233.
Kuhn, D., 1993, Science as argument: Implications for teaching and learning scientific thinking: Science Education, v. 77, p. 319–337.
Kuhn, D., Cheney, R., and Weinstock, M., 2000, The development of epistemological understanding: Cognitive Development, v. 15, p. 309-328.
Kuhn, D., and Pease, M., 2006, Do children and adults learn differently?: Journal of Cognition and Development, v. 7, p. 279-293.
Maloney, J., and Simon, S., 2006, Mapping children's discussions of evidence in science to assess collaboration and argumentation: International Journal of Science Education, v. 28, p. 1817-1841.
Mason, L., and Scirica, F., 2006, Prediction of students argumentation skills about controversial topics by epistemological understanding: Learning and Instruction, v. 16, p. 492-509.
Means, M.L., and Voss, J.F., 1996, Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels: Cognition and Instruction, v. 14, p. 139-178.
Meyer, J.H.F., and Land, R., 2006, Overcoming Barriers to Student Understanding: threshold concepts and troublesome knowledge, *in* Williams, G.C., ed.: London, Routledge.
Millar, R., 2006, Twenty First Century Science: insights from the design and implementation of a scientific literacy approach in school science: International Journal of Science Education, v. 28, p. 1499-1521.
Millar, R., and Osborne, J., 1998, Beyond 2000: Science Education for the Future: London, Kings College, London University.
Orion, N., and Kali, Y., 2005, The effect of an Earth-science learning program on students' scientific thinking skills: Journal of Geoscience Education, v. 53, p. 377-393.
Osborne, J., Erduran, S., and Simon, S., 2006, Ideas, evidence and argument in science education: Education in Science, v. February 2006, p. 14-15.
Perry, W.G., 1970, Forms of Intellectual and Ethical Development in the College Years: A Scheme: New York, Holt, Rinehart and Winston.
Ramsden, J.M., 1998, Mission impossible? Can anything be done about attitudes to science?: International Journal of Science Education, v. 20, p. 125-137.
Rankey, 2003, The use of critical thinking skills for teaching evolution in an introductory historical geology course: Journal of Geoscience Education, v. 51, p. 304-308.
Ryan, R.M., and Deci, E.L., 2000, Intrinsic and extrinsic motivations: Classic definitions and new directions: Contemporary Educational Psychology, v. 25, p. 54-67.
Sadler, T.D., and Donnelly, L.A., 2006, Socioscientific argumentation: the effects of content knowledge and morality: International Journal of Science Education, v. 28, p. 1463-1488.
Simon, S., and Johnson, S., 2008, Professional learning portfolios for argumentation in school science: International Journal of Science Education, v. 30, p. 669.
Taber, K., 2008, Conceptual resources for learning science: issues of transience and grainsize in cognition and cognitive structure: International Journal of Science Education, v. 30, p. 1027-1053.
Toulmin, S.E., 1958, The Uses of Argument: Cambridge, Cambridge University Press.
Trend, R.D., 2001, Deep Time Framework: a preliminary study of UK primary teachers' conceptions of geological time and perceptions of geoscience: Journal of Research in Science Teaching, v. 38, p. 191-221.
—, 2009a, Influences on future UK higher education students' perceptions and educational choices across Geography, Earth and Environmental Sciences (GEES): Journal of Geography in Higher Education, v. 33, p. 255-268.
—, 2009b, The power of deep time in geoscience education: linking 'interest', 'threshold concepts' and 'self-determination theory': Studia Universitatis Babes-Bolyai, Geologia, v. 54, p. 7-12.
Vansteenkiste, M., Lens, W., and Deci, E.L., 2006, Intrinsic versus extrinsic goal-contents in self-determination theory: Another look at the quality of academic motivation: Educational Psychologist, v. 41, p. 19-31.
von Aufschnaiter, C., J. Osborne, J., Erduran, S., and Simon, S., 2008, Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge: Journal of Research in Science Teaching, v. 45, p. 101-131.
Yates, S.J., Williams, N., and Dujardin, A.-F., 2005, Writing geology: Key communication competencies for geoscience: Planet, p. 36-41.