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SUPPORTING ARGUMENTATION THROUGH STUDENTS' QUESTIONS: CASE STUDIES IN SCIENCE CLASSROOMS

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Abstract

The past 15 years have seen a growing interest in the role of argumentation and its role in learning across diverse fields such as computer-supported collaborative learning, language arts, science and math education. Nevertheless, while there is a mounting body of evidence that engaging in the dialogic interaction associated with argumentation helps to develop both student skills with argument and their conceptual understanding, the scientific challenge of understanding how argumentation produces learning remains. A second challenge is that of developing our understanding of how to trigger productive argumentation among students.

Our hypothesis was that developing the skills of questioning – both those of framing an appropriate question and the cognitive demands required to respond to such a question – offered a potential heuristic to facilitate argumentation of a better quality. The purpose of this study, was to explore whether the use of a pedagogy that supports student questioning would foster argumentation in science. Four classes of students, aged 12-14 years, from two countries participated in the study. The students first wrote questions that they had about a problem on heating ice to steam where they had to decide which of two given graphs showing the change in temperature with time was correct. They then worked in groups (members had different viewpoints) to discuss their answers. To help them structure their arguments, students were given an "Our argument" sheet and an argument diagram. One group of students from each class was audiotaped. Data from both students' written work and taped oral discourse were then analyzed. The analysis dealt with types of questions asked, the content and function of their talk, and the quality of arguments elicited. Students' written questions were of five main types: a) key inquiry question; (b) basic or factual information; (c) unknown or missing information that was not provided in the exercise; (d) conditions under which the phenomenon was carried out; and (e) other information, such as the validity and relevance of the given data. To illustrate the dynamic interaction between students' questions and the evolution of their arguments, the discourse of one group is presented as a case study. Emerging from our analysis is a tentative explanatory model of how students' questions helped to generate and sustain dialogue and assist conceptual learning. We conclude by exploring how this model might not only account for existing research findings but also hold predictive value for future research.

Supporting Argumentation through Students' Questions:

Case Studies in Science Classrooms

Introduction

Research has shown that collaborative discussion can contribute to the development of conceptual understanding in science (Howe, Tolmie, Duchak-Tanner & Rattray, 2000; Mercer, Dawes, Wegerif, & Sams, 2004, Asterhan and Schwarz, 2007). Likewise, several studies have highlighted the importance of argumentative discourse (e.g. Kuhn, 1993; Mercer, Dawes, Wegerif & Sams, 2004; Osborne, Erduran, & Simon, 2004a) in the learning of science while other studies have explored the role and value of students' questions (e.g. Chin & Chia, 2004; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). Argumentation and questioning are central to the process of thinking, for as Billig (1996) argues "learning to think is learning to argue" whilst questioning is a process which supports argumentation by helping to engender cognitive dissonance (Festinger, 1957) or "epistemic curiosity" (Berlyne, 1954). Thus, used jointly, argumentation and questioning have the potential to promote critical thinking, foster reflection and deep thinking and the construction of conceptual knowledge. Moreover, the process of scientific inquiry begins with a puzzling observation – essentially an interrogation of nature. A lesson which is initiated with a period of reflective question-asking about a phenomenon, such as that explored in this study, will mirror that process, leading students to generate questions of a causal nature and to formulate explanatory hypotheses that are similar to the "if/then/therefore" form of reasoning commonly found in science (Lawson, 2003).

Argumentation requires students to respond to the claims others make with arguments and counterarguments of their own, constructing explanations, posing questions, and rebutting alternative ideas. In the process of negotiation and coming to some shared understanding, students make argumentative moves such as challenges, counter-challenges, refutations, justifications, and concessions. An interlocutor may also offer a piece of information that triggers an individual to consider its relevance; let it "take hold in [his or] her cognitive environment" (Schwarz, Neuman, Gil & Ilya, 2003, p.26); and subsequently to appropriate or accept it. More importantly, encouraging students to ask questions about the phenomenon under discussion, and of each other, could potentially stimulate more extended and elaborated arguments.

Arguments can also enhance students' epistemic motivation and engagement (Hatano & Inagaki, 2003) and help them to detect and resolve errors (Schwarz, Neuman, & Biezuner, 2000). Furthermore, epistemic activities such as argumentation, questioning and explanation are potentially powerful mechanisms by which students can collaboratively construct new meanings (de Vries, Lund, & Baker, 2002; Roschelle, 1992). As students reason about the advantages and disadvantages, pros and cons, as well as causes and consequences of alternative perspectives, they are exposed to a greater variety of ideas - an activity which can stimulate more extended cognitive engagement.

Considerable work has been undertaken in the field of argumentation over the past decade beginning with the seminal work of van Emmeren (1996), who defined argumentation as "a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint" (van Eemeren & Grootendorst, 2004, p.1). Since then, it has become a focus of those working on computer-supported collaborative learning (CSCL), who have explored its role in 'arguing to learn' and the production of an edited volume with an eponymous title (Andriessen, Baker and Suthers, 2003). In that volume, Jermann and

Dillenbourg (2003) point to the fact that there remain two main challenges for the research community: (a) to understand how argumentation produces learning – that is which "cognitive mechanisms, triggered by argumentative interactions, generate knowledge and in which conditions"; and (b) what are the features of learning environments which "trigger productive argumentation among students?" Work since then, including some of one of the authors of this paper, has focused on the nature of student discussions while engaging in argumentation (Clark, Sampson, Weinberger, & Erkens, 2007; Ryu & Sandoval, 2008, van Amelsvoort, Andriessen, & Kanselaar, 2007; von Aufschnaiter, Erduran, Osborne, & Simon, 2008) in an attempt to gain insights which would answer either one or both of these questions. For instance, van Amelsvoort et al. (2007) showed that the use of diagrammatic representations can improve learning when they are co-constructed, suggesting that they are a heuristic for generating dialogue. A slightly different perspective emerges from the work of von Aufschnaiter et al. (2008) who showed that argumentation consolidated students' existing ideas but did not lead the construction of new knowledge. This finding was similar to that of Veerman (2003, p.140) who concluded that:

> Students need sufficient understanding of a topic and a mutual framework for interpreting each other's information before they can state firm positions and stick to a position. To reach new insights, there must be a certain level of (shared) understanding.

Her view was that direct forms of argumentation are only effective when students are "well-prepared and have a substantial knowledge base" and that more studies are necessary to examine how collaborative learning can both be supported and productive.

Given the body of research conducted on the role of questioning in stimulating conceptual and epistemic thought (see Chin & Osborne, 2008 for an extensive review), it seemed natural to us that engaging in questioning prior to and during argumentation offered a heuristic for scaffolding argumentation of a higher quality – that is, both as a mechanism for clarifying and establishing a body of shared prior knowledge and as an epistemic probe which students could use to force more elaborated explanation and justification.

This study attempts then to advance our knowledge of the role of argumentation in learning in three ways. First, it reports on a pedagogical approach where students with opposing ideas were scaffolded through the requirement to pose questions and to construct their arguments in the context of a scientific phenomenon while working in groups. In this approach, two alternative theoretical explanations of the phenomenon were presented and the students had to decide which of the two given options was more appropriate. The evolution of students' thinking and argumentation was traced to find out whether and how their questions contributed to resolving their differences in thinking and improving their understanding.

Second, students' construction of arguments was supported not only by a set of question prompts but also by the requirement to represent the different components (claim, data, warrant, and backing) diagrammatically. The extensive work conducted by the CSCL community has shown how such devices can assist in scaffolding argumentation (Andriessen et al., 2003). However, despite the increasing prevalence of computer technology in schools, access to such tools is often beset by problems of access or a technical nature or both. Our hypothesis, therefore, was that a paper-based mode of visual representation was more appropriate to assist students to comprehend the nature of their own and other's arguments, and to identify their strengths and weaknesses. Hence, in approaching the design of this study, using such a tool to visualize student argument was incorporated into the students' activity. While computer-supported tools for diagramming and visualizing argumentation have a number of advantages, the study conducted here was essentially exploratory with students and teachers for whom such a process was unfamiliar.

Third, emerging from the analysis of our data is a tentative explanatory model that offers some insights into how argumentation produces learning and aids conceptual understanding. This shows how permitting students to engage in the process of questioning and argumentation opens up many more pathways by which conceptual understanding can be achieved. This model not only offers an explanation, then, for the limitations of didactic exposition but also predictions for future research.

Argumentation in Teaching and Learning Science

Driver, Newton, and Osborne (2000) and Newton, Driver, and Osborne (1999) have made the case for the inclusion and central role of argument in science education, particularly for developing conceptual understanding, improving students' ability to engage in inquiry, and developing an understanding of scientific epistemology. These authors argued that the use of discursive activities that involve students in constructing and analysing arguments about the concepts and applications of science, assessing alternatives, weighing evidence, and evaluating the potential viability of knowledge claims would present a more authentic image of what is involved in scientific inquiry, encouraging students to make links between data, theory and evidence and, in so doing, develop in students a better understanding of the nature of science.

Nevertheless, appropriate conditions and structures where students are encouraged to question, justify and to evaluate their own and others' reasoning must be present in classrooms to enable dialogical argumentation to take place (Duschl & Osborne, 2002). For instance, there must be scaffolds in place to guide students to play intellectual roles that include questioning, predicting, theorizing, challenging others' perspectives, and coordinating theories and evidence, thereby enculturating them as learners into discursive processes that support knowledge construction and metacognition. For argumentation to be supported, there must be the consideration of plural accounts of phenomena and a context which permits dialogical discourse, such as small-group discussion where students build and evaluate explanations. Teaching must also address epistemic goals that focus on how we know what we know, and why we believe certain theories to be superior or more fruitful than competing viewpoints.

The findings of studies by Geddis (1991), Jimenez-Aleixandre & Pereiro-Munoz (2002), Kuhn, Shaw & Felton (1997), Osborne, Erduran & Simon (2004a), Ratcliffe (1996) and Zohar & Nemet (2002) have shown that argument skills can be enhanced by various forms of intervention. For example, Kuhn, Shaw, & Felton (1997) found that, in comparison with control groups, students who had engaged in dyadic discussions constructed a wider range of arguments and alternatives. There was also a shift from simple one-sided to more complex two-sided arguments. Ratcliffe (1996) too found an improvement in the level of students' arguments about decision-making processes in discussions about socio-scientific issues when students used a decision-making framework to guide their deliberations while Zohar and Nemet (2002) found that explicit teaching of argumentation enhanced both biological knowledge and argumentation.

In summary, the implication of this body of work is that argumentative discourse can play a key role in classroom learning. However, students often have difficulties with constructing arguments on their own (e.g. Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kelly, Drucker, & Chen, 1998), and are often reticent about expressing an opinion. Hence, they need to be supported either by explicit instruction or scaffolds such as argument prompts (Bell & Linn, 2000; Simon, Erduran, & Osborne, 2006). In addition, they need to clarify what constitutes relevant pieces of prior knowledge. It is here that questioning can serve an important function.

The Role of Students' Questions in Argumentation

The ability of students to pose appropriate questions to guide their thinking and to reflect both on their own and others' ideas is an important skill to acquire (Kuhn, 2009). Indeed, an active, interrogative approach to learning is one of the indicators of engaged learning (Chin & Osborne, 2008). For example, if students are confronted with the issue of having to make choices among different plausible options, or if they want to challenge the validity of a proposed statement or idea, they would need to interrogate various aspects of the phenomenon at hand. In the process of undertaking this task, they can ask questions that would help them become aware of what they do not understand, compare the pros and cons of competing ideas, recognise any inconsistency or faulty reasoning, formulate and test hypotheses, evaluate the evidence that supports or refutes the hypotheses, and generate alternative explanations or ideas that are more viable. These kinds of activities are a core feature of the recommendations of *Taking Science to School* (Duschl, Schweingruber, & House, 2007) which argues that science should be seen as a cycle of producing evidence, generating explanations, and conducting evaluations. Students' questions could then provide the critical scaffolds to initiate meaningful argumentation and critical thinking about possible explanatory hypotheses and the evidence which may, or may not, support them.

When students pose questions about things that they want to know, they become more cognizant of what they do not know or are puzzled about. Posing questions, either to themselves or to their peers, may then scaffold their thinking by acting as a "thought-starter" and meta-cognitive or epistemic tool. Such a process would then have the potential to broaden: a) the "argumentation space" (Erduran, Simon, & Osborne, 2004) in terms of the nature and frequency of argumentation patterns; b) the "questioning space" in terms of the types, depth, range, and frequency of questions; and c) the "negotiation space" in terms of the multiple perspectives and range of arguments used. As a corollary, it should then facilitate knowledge construction. However, when generated spontaneously, students' questions are usually infrequent and shallow (e.g. Graesser & Person,1994; White & Gunstone, 1992) rather than those of a higher level which require inferences, multi-step reasoning, and the application and synthesis of ideas. Thus, for students to fruitfully ask productive questions, they may either need explicit training (e.g. King, 1990), additional scaffolding or both.

Supporting Argumentation with Diagrammatic Representations

Considerable work has been undertaken in the past decade by the Computer Supported Collaborative Learning (CSCL) community to develop software tools that either enable the visualization of argument (e.g, Belvedere and Digalo), or that scaffold argument by making critical epistemic requests for evidence or deliberation while engaged in the process of inquiry (e.g., WISE). These tools, which include computer-based diagrams, have served to make students' thinking visible and, by acting as resources for conversations and reasoning, have made significant contributions to the study of argumentation (e.g., Baker, 2003; Linn & Bell, 2000). Suthers (2003) demonstrates that such tools help to initiate negotiations of meaning through shared representation, serve as a proxy for the purpose of gestural deixis, and provide a foundation for implicitly shared awareness.

The work of Walton and Godden (2005) and Walton and Reed (2003) has also explored the use of the combination of argument diagramming *and* critical questions in the study of argumentation. Their models represent argument on a diagram with an arrow joining a set of premises to a conclusion. Critical questions then allow the user, who may be the interlocutor or respondent, to probe into the various aspects of an argument. In this respect, they function as heuristic devices to stimulate dialectical thinking and guide arguers in their evaluation of arguments, especially when the issue to be settled by argumentation hangs on a balance of considerations.

The Research Aim

Most of the studies carried out to date on teaching students' questioning have been for the purpose of improving reading comprehension of text (e.g. Costa, Caldeira, Gallástegui, & Otero, 2000; Koch & Eckstein, 1990), generating researchable questions for science investigations (Cuccio-Schirripa & Steiner, 2000; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005), or for guiding project work (Pedrosa de Jesus, Neri de Souza, Teixiera-Dias, & Watts, 2005). In addition, where students were taught to generate higher-order questions, the questions and the dynamics of the questioning process were rarely analyzed. Little, if any, research has been reported on teaching or scaffolding students in questioning where the purpose is to develop students' skills in argumentation or reasoning about issues where multiple perspectives have to be considered. Hence, it was hypothesized that supporting students in question-asking could stimulate them to engage in productive argumentation, in the sense that it would lead to enhanced conceptual understanding, and that higher-order questions would be productive in triggering argumentation.

The purpose of this exploratory study, then, was to trial some pedagogical strategies that teachers could use to encourage and scaffold student questioning and thinking in classroom discourse. These strategies included the use of questioning prompts and an argument diagram for collaborative group tasks. The argument diagram provided was a generic outline of the structural elements of an argument to which further details could be added. It was included to help students organize their thinking visually, as well as linguistically and to offer a focus for argumentation. We sought to determine the extent to which their implementation led to enhanced quality in students' arguments. Thus the research question, which forms the focus of this study, was:

- Does the opportunity to ask questions encourage critical thinking, promote reflection and engage students at high levels of argumentation (e.g. formulate chains of reasoning, consider evidence, provide justifications, examine the reasonableness of their assertions, consider alternative perspectives, question the validity and reliability of data, etc.), lead to good quality verbal discourse, and develop students' conceptual understanding?

Methods

Setting for the Study

This study involved the participation of four classes of students aged 12-14 years learning science. Two classes (years 7 and 8) were from two schools in Singapore, while the other two classes (years 8 and 9) came from two schools in London, England. Table 1 summarizes information about the participants of the study. The two schools in Singapore are referred to as S1 and S2, while those from England are referred to as E1 and E2. School S1 was a coeducational high school with boys and girls, while school S2 was an all-girls' high school. Both were "autonomous" schools in that they enjoyed greater independence than mainstream schools in the implementation of school programmes and administration to enable them to provide a wide variety of innovative and enrichment programmes. These schools generally admitted students of average or above-average ability. However, they differed from the more elite “independent” high schools which set their own fees, and which attract students of the highest ability. School E1 was a comprehensive high school and school E2 was an all-boys’ selective high school which recruited students from the top 20% of the ability range. The teachers from schools S1 and S2 are referred to as ST1 and ST2, while those from schools E1 and E2 are ET1 and ET2 respectively.

[Insert Table 1 about here]

In selecting the classes for the study, teachers were told that the students needed to have some prior knowledge of the particle model of matter for water in the solid, liquid and gaseous states. However, it was important that they had not undertaken any activity to measure the variation in temperature as water changes state from ice to water vapor or been taught about this phenomenon in other ways; otherwise, with a knowledge of the well-established and consensually agreed answer, there would be little to discuss or argue about. Briefing and data collection for each class was conducted over one session, which ranged from 1 to 1.25 hours for the schools in London and 2 hours for the schools in Singapore. The difference in times was due to the varying amounts of time that the teachers were able to spare in granting the researcher (Author 1) access to their classrooms to conduct the study.

Procedure

All the four teachers were briefed on the approach to the lesson so that there would be some uniformity in the way they carried out the activity. The first phase of the lesson began by introducing the vocabulary associated with ideas in science such as hypothesis, prediction, and theory and explaining the concept of argumentation in science. Terms such as data, evidence, reasons, qualifier or conditions, backing or assumptions, counter-argument, and rebuttal, as well as the importance of providing justifications and thinking of counter-arguments that challenge another's argument, were explained and illustrated with specific examples. The importance of asking questions when making claims, evaluating arguments, and making decisions was also emphasized and illustrated, with the teachers providing the students with generic question stems (King, 1990) and examples of how to use these to ask questions. While the focus on the nature of language is not a normative practice of school science, such meta-linguistic concepts are, we believe, important tools for mediating student understanding of the linguistic function of such statements. Furthermore, the introduction of such vocabulary provided students with a working language to articulate their ideas. The students were found to use words like "data", "evidence", "reason", "counter-argument", and "rebuttal" in their dialogues, and their reference to these components of an argument helped them to structure and focus their thinking systematically.

After the teachers had completed their briefings on how to structure an argument and how to ask questions, the students then worked on a given task that required them to decide which of two given graphs (A or B) best represented how the temperature would change as they heated ice to steam. This task was originally developed by a teacher and used by Osborne, Erduran, and Simon (2004b) in the pack they produced for teacher professional development. The task was presented on a task sheet titled "Heating ice to steam" (figure 1), together with a list of evidence statements (figure 2). Students were asked to evaluate the evidence which could support one graph or the other, or both. They were also expected to provide justifications for their choice of graph using the evidence from the given statements and anything else they thought was relevant.

[Insert figure 1 about here]

[Insert figure 2 about here]

Students were given a list of question prompts (figure 3) to initiate and scaffold the question-asking process, and encouraged to ask any questions that they had based on the given task. These question prompts were adapted from the framework given in Chin (2006) that aims to foster thinking in students through self-questioning. They were designed to focus students' attention on important aspects of the given problem, and to model the kinds of questions that students ought to be asking themselves.

[Insert figure 3 about here]

To avoid the situation where students came to an agreement very quickly without any need for discussion or argumentation, the teacher quickly conducted an initial straw poll to find out which students held each of the opposing ideas (i.e. graph A or B) so that he or she could assign students with different viewpoints to the same group. Group assignment was done such that members had plural perspectives, yet were able to work cordially. The students then worked in groups of three to six students to pose questions related to the given task, discuss their views, and to comment on each others' ideas during a group discussion. The variation in group size was due to the different class sizes between the schools in England and Singapore (see figure 1). To encourage dialogic interactions among students, a number of structures involving group work were used. Each group had a group leader and a scribe. The group leader had to ensure that every group member contributed to the discussion while the scribe recorded written questions and answers onto the given worksheets. Students were reminded that, at any one time, only one person would talk and that the other members would listen. Also, that differences in ideas were normative, and should not result in personal adversarial conflicts.

Within each group, students first worked individually during an initial "think-time" (about 5 min) to brainstorm and write questions about the graphs. At this point, they did not have to answer their questions. This phase was designed to force students to think of questions that were relevant to the problem. The group members then took turns to pose their questions while the scribe recorded their pooled questions onto the Question Web provided. The latter was a graphic organizer resembling a spidergram where students documented their questions. Using the Question Web and the set of question prompts provided, students put questions to each other while they used the given evidence statements that were relevant to their arguments, as well as their other ideas, to justify why they believed their choice of graph was the correct one. At this stage, students were reminded that they had to provide evidence for their claims as well as for their counter-arguments.

To help them structure their arguments, students were given an "Our argument" sheet containing writing stems which required them to state their claim, data or evidence, reason(s) for their answer, counter-argument and rebuttal (figure 4). They worked collaboratively to write their arguments for their view of which was the correct graph. Finally, each group was also required to represent their argument in graphic form using an argument diagram (figure 5), which was based on Toulmin's (1958) structure of an argument. The diagram comprised a series of statements and arrows in which one statement was the conclusion and the others were premises supporting this conclusion, and depicted the linkages between the claims, data, evidence, justifications, backing, and qualifier. As such it helped students visualize the structure of an argument as they verbalized their ideas during the writing activity towards the end of their discussion.

[Insert figure 4 about here]

[Insert figure 5 about here]

From each class, one group of students was selected for audio-taping. The selection was made by the teacher based on the criteria that the chosen students should be (a) verbally expressive so that the discourse could be captured on tape; (b) likely to stay on-task; (c) able to work with each other cordially; and (d) hold opposing viewpoints on the answer in the given task. All the four groups that were audio-taped comprised three students with different viewpoints about their choice of graphs. The group size was kept to three to facilitate transcription of the audiofiles. The four groups from the four schools E1, E2, S1, and S2 are referred to as EG1, EG2, SG1, and SG2 respectively. All the teachers' briefings, as well as the taped group discourse from each of the four classes were transcribed verbatim.

Analysis of Data

Data from both the written work of students and their taped oral group discourse were transcribed. Initially, the collective questions from all the Question webs were analyzed to get a sense of the kinds of questions that students posed using a grounded looking for emergent patterns. The verbal discourse from each of the four groups was also transcribed, then examined to find out how the questions that students asked influenced the evolution of their ideas and thinking about the concepts related to the graphs. The transcript of each group discussion was segmented into argumentative episodes. Each episode began with a student's question that initiated a substantive idea or line of discussion and the subsequent group talk elicited by this question. In such an episode, the proponent and the respondent(s) take turns making moves which take the form of speech acts. Typical moves include asking a question, making a claim, putting forward an argument with justifications, and challenging opposing ideas. Each utterance in an argumentative episode was then coded as a question or component of argument. As such, the linguistic analysis focused on both the content and function of talk. Analyses of data included examining the number and types of questions, as well as the number, types, and quality of arguments elicited (as assessed by the evidence given and the multiple perspectives provided). The role of the posed questions and the thinking underlying each utterance was, of necessity, inferred and examples of how this was done are shown in the presentation of the results.

Argumentative discourse was analyzed using a modified version of the Toulmin Argument Pattern (TAP) analytical framework developed by Osborne, Erduran, and Simon (2004a) and Erduran, Simon, and Osborne (2004). The quality of the arguments was judged on the depth of explanations given, the elaborateness of the warrants or grounds cited, the appropriateness of any examples used as justification, and the presence or absence of rebuttals used to refute opposing ideas. The framework used for argumentation is described in Table 2.

[Insert Table 2 about here]

The four categories of arguments are referred to as "types" instead of levels, where Type 1 is the most basic, and Type 4 is generally more elaborate and developed. Type 4 arguments contain a rebuttal (4A) which opposes another individual's argument or a self-rebuttal (4B) where the individual considers the limitation in his or her own argument. The arguments get progressively more sophisticated from Type 1 to Type 3. However, there is less of a distinct hierarchy between Types 3 and 4. This is because Type 3 arguments could contain strong justifications with grounds that are more detailed and comprehensive than Type 4 arguments, which could be less elaborate. Thus, Type 4 arguments are not necessarily considered to be at a higher level just because they contain a rebuttal, since their justifications could be weaker despite the presence of a rebuttal. Argumentative episodes were also analyzed for the relationship between any questions posed and the components of arguments elicited (such as claims, counterclaims, data, warrants, and backing). From this process, the main themes and features of the data were identified.

Results

We first report on the different kinds of questions that were written by the 29 groups from all the four classes. Following this, we present an analytic summary of the types of questions and arguments generated by the four target groups that were audio-taped. We then focus on the case of a successful group to illustrate the kind of productive discourse that is possible when group talk revolves around students' questions, and which shows the dynamic interaction between students' questions and the evolution of their arguments.

Questions Posed by Students in Written Form

Table 3 summarizes the kinds of questions that students wrote in their Question webs and shows the wide diversity of questions that the activity elicited. The questions were categorised based on an inductive analysis of the kinds of information that students wanted to know in order to arrive at a consensus regarding the problem posed in Figure 1. These categories comprised questions that sought: (a) key explanations for patterns in the graphs; (b) basic or factual information; (c) unknown or missing information that was not provided in the graphs; (d) conditions under which the heating of water was carried out; and (e) other information, such as the validity and relevance of the given data.

[Insert Table 3 about here]

"Key inquiry" questions sought *explanations* and were mainly overarching "Why?" questions that reflected puzzlement about cause-effect mechanisms pertaining to the pattern in the graphs and why things behaved the way they did. These questions sought reasons for the shape of the graph, the flat portions corresponding to 0 ^{o}C and 100 ^{o}C, the differences in the rate of temperature change, why the temperature decreased below 0 ^{o}C for ice, and why the temperature increased beyond 100 ^{o}C for steam. They were the "driving" questions that appeared in most of the Question webs, that addressed the big ideas embodied in the phenomenon of heating ice to water, and that subsequently steered the direction of student talk in their groups.

"Basic information" questions addressed *factual information* pertaining to basic scientific concepts. They indicated that students were aware that they needed to know some fundamental information first before they could answer the above key inquiry questions. These questions pertained to the melting point of ice, the boiling point of water, the basic properties of a graph, and the particle theory. Questions in the "unknown or missing information" category indicated that students were *questioning assumptions*, were aware that some information was unknown or missing and that they needed this information before they could arrive at an informed answer. These questions dealt with the heat source, whether impurities were present, the surroundings in which the heating was carried out, the room temperature, the volume of ice used, and the surface area of the container used.

Questions in the "conditions" category showed *predictive thinking* in that students wondered what would happen if the conditions under which heating occurred were changed. They addressed speculations about changes in conditions such as intensity of the flame, room temperature, amount of ice used, and the time of heating. Finally, the questions grouped under "others" pertained to miscellaneous types of information. They included questions interrogating the *validity and relevance* of the given data and evidence. Sample questions representative of each category are given in the table. They are quoted verbatim, without being edited for grammatical errors. Questions that are quoted directly are indicated with a tick (✓), whereas questions that addressed a similar idea are marked with an asterisk (*).

Questions and Arguments Generated Orally by the Target Groups During Discussion

For the four target groups that were audiotaped during group discussions, the number of questions asked in each category, as well as the type of arguments constructed, are summarized in Table 4.

[Insert Table 4 about here]

For group EG1, the teacher interrupted the group's discussion several times during the lesson to talk to the whole class, and this forced the group to suspend their talk every now and then – a factor which may explain the disparity in the results.

Although all the four target groups eventually came to a consensus that graph B was the more appropriate answer, groups EG2, SG1, and SG2 displayed a relatively higher quality of talk than group EG1, in terms of the number of questions and arguments generated. These three more successful groups asked a greater variety of questions across the range of question types, most of which addressed the key inquiry concepts, basic information, and the elements of an argument (e.g., "What is your evidence for this?"). In contrast, group EG1 asked a narrower range of questions, none of which referred to unknown or missing information, or the components of an argument.

The three more successful groups (viz., EG2, SG1, and SG2) also produced more arguments, with a range of types and also with more sophisticated arguments illustrative of types 3 and 4. While groups EG2, SG1, and SG2 constructed a total of 19, 13, and 11 arguments respectively (which included 5, 5, and 3 Type 4 arguments containing rebuttals), group EG1 generated only six arguments pitched at Types 1 and 2.

The analysis found that productive discourse of the more successful groups was characterized by:

a) questions which focused on the key inquiry ideas and a greater variety of salient concepts,
b) an explicit and conscious reference to the structure and components of an argument,
c) a continual elaboration and expansion of the arguments constructed, and
d) a prevalence of exploratory talk.

Students' questions prompted the students to articulate their puzzlement, make explicit their claims and alternative conceptions for peers to respond to, identify and relate relevant key concepts, construct explanations, and consider alternative propositions when their ideas were challenged.

In order to exemplify the nature of such discourse, what follows is an in-depth study of group SG1. This group is chosen because it illustrates what kind of discourse is possible when such an approach is used. It should not be read as typical but rather as an example of the kind of productive discourse can be generated with tasks that combine the use of questioning and argumentation.

Case Study: The Group of Students from Teacher ST1's Class

This group's discourse was rich and illustrates the circuitous route and detailed thought processes that the students engaged in before reaching a consensus in their answer, as well as the evolution in their ideas during a process of conceptual change. In the examples that follow, […] denotes a brief pause, "…" indicates an omission of irrelevant words from within a sentence, while "…." represents the omission of irrelevant words from one or more sentences. Students' questions are highlighted in italics.

This group comprised three students, all of whom were ethnically Chinese: Jiahao (J), Xunzhou (X), and Sarah (R). At the beginning of the activity, Jiahao believed that graph A was correct while Xunzhou thought that graph B would be more appropriate. Sarah thought that neither graph was correct and drew her own version of a graph which she labelled as C[1]. Indeed, one potential improvement to the task would be add such a third graph to the task. However, the task was used on the recommendation of a teacher and used as is. Graph C depicted a straight line with a positive gradient arising from the origin followed by a horizontal plateau at 100 ^{o}C after a period of time. It did not show the temperature going below 0 ^{o}C or above 100 ^{o}C. However, at the end of the activity, both Jiahao and Sarah changed their minds and became convinced that graph B was correct.

What was it in their group dialogue which made these two students change their minds? An analysis of their discourse transcript showed that the students' questions, when used as a rhetorical device as part of the dialogic exchange, played an important role in generating and sustaining further talk. In particular, it was the questions arising from the students' puzzlement about various aspects of the graphs that elicited both arguments and explanations. In attempting to answer their questions, the students generated claims and arguments about their ideas which paved the way towards resolving their disagreements. Over time, they constructed progressively

[1] The task was used as is on the basis of a teacher recommendation. There is no doubt that a third graph C which does not show the temperature going below 0 ^{o}C or above 100 ^{o}C might have been valuable in providing an additional hypothesis for consideration.

more sophisticated arguments, which moved from Type 1 to Type 2, and then to Type 3 towards the end of their discussion. Examples of these different types and quality of arguments are given in the excerpts below, with the argument codes highlighted in bold. The students' discussion also revolved around the structure and components of an argument. This was manifested by their reference to the claim (e.g., "So which one do you all think is better – A, B,, or neither A nor B?"), data and evidence (e.g., "What is your evidence for this?"), warrant (e.g., "What is the reason?"), qualifier (e.g., "Are there any impurities in the ice?"), and rebuttal (e.g., "If someone does not agree with us, then how would we convince him or her?").

The group's discourse could be divided into three main phases, characterized by the following features:

Phase 1 (Pre-argumentation: Generation of Questions)

- Noting the stimulus presented
- Observing and interrogating the given data
- Generating questions which are stimulated by puzzlement and cognitive conflict

Phase 2 (Argumentation: Addressing each others' questions and constructing explanations)

- Responding to the self-generated questions and addressing points of disagreement
- Exploring ideas and constructing mini-explanations in "bits and spurts" ("ideas-in-pieces")
- Making claims, counter-claims and counter-arguments
- Making rebuttals and self-rebuttals
- Constructing increasingly more developed explanations and self-explanations which comprise data, evidence, warrants, qualifiers, rebuttals, and/or self-rebuttals

Phase 3 (Consolidation: Resolution of opposing ideas)

- Consolidating the disparate ideas into a formal argument

- Building coherence into a proposed theory

The sequence mirrors in many ways the initial steps of scientific inquiry – that is, the perception of a puzzling observation, the identification of causal questions, and the construction of explanatory hypotheses. As will be seen from the dialogue, that students were engaging in a form of thought experiment by testing their ideas against their knowledge of the world.

Phase 1 (Pre-argumentation: Generation of questions)

This phase began with the students looking the given graphs and question prompts, and then posing questions which addressed the substantive feature of the phenomenon portrayed by the graphs. These "key inquiry questions" related to whether there would be two flat portions on the graph where the temperature remained constant for a while, and whether the temperature of ice and steam could go below 0 ^{o}C and above 100 ^{o}C respectively. By articulating their questions aloud, the students made public their puzzlement.

R: The temperature, right […], it started like below 0 ^{o}C…. But if you take it out [from the fridge], it's already like 0 [^{o}C]. *How come it's like below 0 ^{o}C?*

X: No, it can be below 0 ^{o}C…. When you put it [ice] into the fridge, it's less than 0 ^{o}C…. My first question is "On the graph B… *Why [does] the graph have a curved line from the point where it started increasing from 0 ^{o}C to the point it arrived at 100 ^{o}C?....*" My second question is "*Why does the temperature of the water stay constant at 100 ^{o}C before it increases some more?*". Then…. the last question is… "*How high can the steam go before it stops increasing its temperature?*"….

J: Okay. My question…. I just want to ask "*Is the ice being heated with constant heat or does it vary?*" And also "*What is the steam's temperature?*"….. And my last question is

"*Is [are] there any impurities in the ice?*" Because if there is, it will actually slow down the heating too. I'll pass it to Sarah.

R: Uhm, there are just two questions I want to ask. The first question is "*In graph B, in … two certain parts, the temperature just stays constant…. Then it started increasing. I want to know why?….*" Then the second question is "*Is the ice directly heated when it is taken out of the freezer or is it left out for a while before heating?*". *If it is left out, how long has it been left out?*

In the above excerpt, Sarah's observation (that the temperature of ice was initially below 0 ^{o}C) puzzled her resulting in a question which elicited an explanatory response from Xunzhou ("No, it can be below 0 ^{o}C…. When you put it [ice] into the fridge, it's less than 0 ^{o}C"). This was merely a claim (**A_C, Type 1**) without any grounds. Following this interaction, the other two students took turns to verbalize their questions. Xunzhou's questions sought explanations for the shape of the graph while Jiahao and Sarah also questioned assumptions about the conditions under which the ice and water were heated such as whether the heat source was constant, whether impurities were present, and whether or not the ice was heated immediately after being taken out from the freezer. These questions set the stage for what was to come after and shaped the dialogues that followed.

Phase 2 (Argumentation: Addressing each others' questions and constructing explanations)

The students then tried to answer their own questions and to figure out whether the temperature of water could go above 100 ^{o}C and below 0 ^{o}C. During this stage, they constructed piecemeal mini-explanations in "bits and spurts", comprising "ideas-in-pieces" (diSessa, 1988). In their attempt to work towards a coherent framework to make sense of the graphs, they had to first address some basic information and fundamental ideas about the changes in state of water, such as what the temperature of steam was, and whether the temperature could remain constant for a while at 100 ^{o}C and 0 ^{o}C instead of continually rising even though the water was being heated. Aided by the question prompts provided, the students also articulated their observations about the graphs A and B and described their features.

Making sense of the graphs.

R: Okay, let's answer some of the questions…. So we give our reasons…. All of us have different…. ideas, different views. *So which one do you all think is better – A, B, or neither A nor B?*…. [Graph] A…. it's continuously going up. And then B… it stays constant, and after a while, it will increase.… But for my graph [C]… the end of the graph stays constant at 100 ^{o}C, or a little bit more. It doesn't really go that high.

X: But I still support B…. *Have you heard of super-heated steam that is over 100 ^{o}C?*

R: Yeah…. But at the end of the day, it [temperature] will be constant….

J: *Why must it be constant? Why not shoot up more?*

R: *Why not shoot up more?* Uhm, it also actually depends on how long it takes.

J: What you say about being constant is the water. About the steam, I'm not quite sure… unless you all know the temperature of the steam….

J: Well, Xunzhou, *do you still go with B?*

X: Yes, I still go with B.

J: *Why?*

X: Uhm…. During 0 ^{o}C… the water actually stays at the same temperature because at that period of time, the ice may not melt all the way… If there is ice, then the ice must be at least at 0 ^{o}C. So it will stay constant. Not like [graph] A when it's just 0 ^{o}C, [and] the next moment, it increases its temperature again.

Here, Sarah found it difficult initially to believe that the temperature of water could rise above 100 ^{o}C no matter how much it was heated, but Xunzhou challenged her thinking by asking her whether she had ever heard of super-heated steam. When Sarah maintained that the temperature would stay constant at 100 ^{o}C, Jiahao asked her why that had to be so and "Why not shoot up more?". Sarah then reconsidered and decided that "it also actually depends on how long it takes". Jiahao then followed up by saying that they first needed to know the temperature of steam before they could decide whether the temperature could rise above 100 ^{o}C . Subsequently, when Xunzhou was asked to explain his choice of graph B, his last statement in the episode above (**A_G+R, Type 4A**) showed his first attempt to explain why the temperature of ice would stay constant at 0 ^{o}C for a while before increasing further. He also rebutted the possibility of graph A being correct as it showed the temperature increasing continuously when ice was still melting. As we shall see later, he subsequently developed this idea into a more complete one.

The researcher (Author 1), who happened to be walking by the group, then asked the students whether they thought there might be some occasions when the temperature could go above 100 ^{o}C leading to the following interaction.

A1: Do you think that there are any conditions when the temperature can go above 100 ^{o}C?

J: Yes. *Like, for example, when you add something in, some substance, like salt. Perhaps the temperature will go higher. Don't you think so?*

R: Yeah. But the problem is that down here, they didn't say you are going to add salt. So you don't know whether they did add salt or not. So you cannot conclude that the thing [temperature] will continue increasing.

At this point, there was a small breakthrough in Jiahao's thinking, when he proposed that the temperature might remain constant for a while during melting and boiling. Challenged by Sarah to account for the rise in temperature beyond 100 ^{o}C, Xunzhou suggested that "something" was added to the water.

J: Actually, come to think of it, I am quite supporting graph B because there is […]

R: Huh, huh (laughs)

J: I'm not totally convinced yet, okay? It's because at 0 ^{o}C, there is this constant temperature there. And I believe that the actual melting process is there. And at the 100 ^{o}C one, it's actually the boiling point.

R: Uh-huh. Yeah. *But since you say it's already the boiling point, why is it [temperature] continually increasing?*

X: I think they actually added something in to make the temperature increase.

The conditions under which water is heated.

By this time, Sarah had resolved her initial puzzlement about how ice could be below 0 ^{o}C. For a while, the students struggled to explain why there were two flat portions when the temperature remained constant at 0 ^{o}C and 100 ^{o}C. Xunzhou then hit on the idea that it was necessary for them to know the conditions under which the water was being heated, such as whether the water was in a container with or without a lid.

R: I agree with you in this part… when you take it [ice] out of the fridge, it's below 0 ^{o}C….
I want to know why one period in graph B, right, the temperature is just constant….

X: At the 100 ^{o}C point?....

J: At the boiling point…. Perhaps, the boiling is in progress....

X: *But I'd need to know if the water is placed in a … pot with a cover on it?*

R: With or without cover.

X: Yeah, open or without cover. Because with the cover, then heat will not escape. Heat will enter the pot, into the water. But then when the heat wants to escape, it wouldn't escape so easily. So the heat must be converted into some other form. So the water may increase to a higher temperature.

This last statement by Xunzhou (**A_{G+}, Type 2**) was his attempt to explain why the temperature of the boiling water might increase above 100 ^{o}C and was a *self-explanation*, generated in response to his own question posed earlier. Subsequently, the students also questioned their own assumptions and identified several pieces of "missing information".

X: So actually… we need [to know] all the conditions…. They didn't actually show us what's the timing and whether they added anything inside. And what are the variables they changed and they didn't change. So we're not really sure whether the experiment is fair or how they actually carried out the experiment…. They said heated ice to steam. So you don't actually really know whether they put the ice into the pot. And then they just boil the ice and then get all steam….

R: Or they actually let it melt first…. So it's actually quite vague.

The students' thoughts about the conditions under which the heating was carried out - essentially a consideration of the limits or the qualifiers to their argument. Xunzhou then tried to further articulate his explanation for the portion of the graph which depicted the melting of ice at 0 ^{o}C. In this second attempt, his argument (**A_{G+}, Type 2**) was slightly more detailed than the one that he had given earlier.

X: At the start of the experiment, the temperature of the matter was below 0 ^{o}C…. the water should be in its solid form, ice.... The temperature will start to increase, then it stays constant for a while…. If you have a pot and it is pre-heated, and you put the ice inside, it [ice] starts to melt. There's part of it which is still ice. So it must still be 0 ^{o}C until all the ice has melted, then it [temperature] will still increase....

On the verge of changing their minds.

Following this exchange, Jiahao again mentioned that he was getting closer to believing that graph B was the correct answer but that he was still not totally convinced. Sarah added that she too was on the verge of changing her mind, and for the first time, reasoned that the flat portion of the graph depicting "no temperature change" could be due to energy "being used to break bonds between particles" (**A_{G+}, Type 2**). By using the concept of molecules for the first time, she had now begun to think at the sub-microscopic level. Previously references to the problem had only been pitched at the macroscopic level.

X: Jiahao, *are you still supporting A or are you supporting B? Or neither A nor B?*

J: I am at the point of changing my position…

X: To?

J: B, but not so fast.

R: Okay. Yeah, me too, because I'm kind of convinced but not really, really in a sense convinced. Because, as the paper states, energy is being used to break bonds between particles. Then there will be no temperature change. But the problem is the temperature is increasing (referring to the slope showing temperature increase).

J: That's because perhaps it has finished breaking its bonds between the particles.

R: Uhm, so you agree with B. So all of us kind of agree with B.

Building on the idea of "bonds between particles", Junhao reasoned that the constancy in temperature was due to the water having "finished breaking its bonds between the particles". Xunzhou then followed by generating a more elaborate explanation, making further use of information in the given Evidence statements.

X: On the piece of paper titled Evidence statements, the fourth line, it says that energy is needed to break bonds between particles. So… at the start of the experiment, it was ice. So the heat was used to break the ice into liquid form first. So there was no heat used to increase the temperature but most of it was used to change the form. So it must stay constant for the period when it was changing into liquid.

R: Okay, that was kind of precise.

X: And I think that when it comes to the 100 ^{o}C point, it stays constant too because it's changing from liquid form to gaseous form.

R: So you think that it will stay constant for a while so that in a sense, there is time for the liquid to change to gas.

X: Yeah. It needs the heat energy to change from liquid to gaseous [form].

J: Thus, the temperature rises. *Is that what you are saying?*

X: Uh, yes. No. After it changes to gaseous state, then it rises.

J: *Why does it rise? Just because it's in [the] gaseous state?*

X: (thinking hard and verbalizing slowly and thoughtfully) Because the heat energy is used to change the state of the liquid. So after it changes its state, then it [temperature] will shoot up. The heat energy must be used […] must be changed to some form somehow. So in my opinion, I think that the energy supplied, after it changes from liquid state to gaseous state, would be used to increase the temperature.

In the last statement above, Xunzhou repeated his explanation of why the temperature would stay at 100 ^{o}C before rising further. This time, the argument that he constructed (**A_{G++}, Type 3**) invoked a deeper level of conceptual thought which was an improvement on his previous ideas.- one which is both more complex and more elaborated with more ideas and justifications and essentially the canonical scientific explanation. The important feature of note is that student generated questions are a core and integral feature of this dialogue.

Another feature of this excerpt is that the three students co-constructed an explanation, with each individual verbalizing a part. Here we see Sarah being the first to apply the concept of energy being used to break bonds between particles. Then Junhao augments this idea by suggesting that there is an end to the bond-breaking phase. Junhao's ensuing question to Xunzhou, then leads a consolidation of the idea where he makes the link between bond-breaking and change of state, thus generating a more detailed explanation of why the temperature of water stayed constant at 100 ^{o}C before increasing further.

At this point, Sarah was beginning to change her mind to accept graph B as the correct answer. Junhao was still not totally convinced, however, and offered a rebuttal, giving the example that if the ice were dropped into a vessel at an extremely high temperature, the temperature "will immediately shoot up" (**A_G+R, Type 4A**). Sarah now believed in graph B but she thought that it had something to do whether the lid of the container was present. Xunzhou then followed up on this idea by arguing that if the container were open without a lid, then the temperature would remain constant without going up beyond 100 ^{o}C.

By this point, Xunzhou's explanation (**A_{G++}, Type 3**) had grown progressively more elaborate and even recognising the different possible scenarios, depending on whether the lid on the pot was on or off. He did, however, qualify his reasoning by saying that the temperature of water in the gaseous state would not rise beyond 100 ^{o}C if the pot were left open and if steam were allowed to escape continuously.

Phase 3 (Consolidation: Resolution of opposing ideas)

After attempting to answer their own questions, these students now came to some resolution of their ideas. The requirement to complete the "Our argument" sheet and the argument diagram initiated a transition to Stage 3 where they were guided to address explicitly their arguments in a more structured way. It was during this time that Jiahao decided to change his mind and choose graph B as the correct answer instead of A. However, he also argued that the graph could be A if an incinerator were used. In such a case, the temperature would be so hot as to cause the ice to melt instantly, and the time taken for melting would then be almost negligible, thus registering no horizontal portion on the graph.

J: Alright, I think it is time for me to take my hat off to Xunzhou because right inside the evidence statements, it clearly states that *energy is being used to break down bonds between the particles* [BACKING]. Then there will be no temperature change…. Alright. I think I agree with Xunzhou…. *[If] the ice is actually being thrown down into an incinerator, perhaps, then I think the answer will be graph A* [QUALIFIER]. But in these circumstances, *I think it's graph B* [CLAIM] because the evidence statements state that there will be no temperature change when there is bonding [bond] breaking of particles. And at the 0 ^{o}C and 100 ^{o}C, it is obvious that they are breaking their bonds, changing from liquid… so it is very obvious that the answer is graph B. *Because at 0 ^{o}C, there's definitely a breaking of particles [bonds], changing from solid state to liquid state. And that's why there is no temperature change* [WARRANT, DATA].

In the above excerpt, Jiahao's argument (**A_{G++}, Type 3**) is complex and includes the correct claim (e.g. "I think it's graph B"), data (e.g. "there is no temperature change"), warrants (e.g. "because at 0 ^{o}C, there's definitely a breaking of particles [bonds], changing from solid state to liquid state. And that's why there is no temperature change"), backing (e.g. "energy is being used to break bonds between particles"), and qualifier (e.g. "[If] the ice is actually being thrown down into an incinerator, perhaps, then I think the answer will be graph A").

Guided by the "Our argument" sheet and the argument diagram, the students then proceeded to discuss the details of their argument in a more structured manner by addressing the components of their argument using the appropriate terminologies and by formally writing them onto the sheet. Although the argument sheet contained only writing stems and no questions, the students once again generated their own questions.

R: (Referring to the data/evidence section of the argument sheet) *Then what is your evidence for this? Why did you choose B instead of A?....* We choose graph B. It's because […]

J: There is no temperature change at the 0 ^{o}C point indicating that there is the breaking of bonds between particles…. Causing the ice to change from solid state to liquid state.

R: Okay. Let's go on to the next question. *What is the reason?*

X: It's because…. The evidence of the breaking of particles supports our idea of choosing B graph because there must be a moment when a matter changes from […]

J: One state to another.

X: That's right, Jiahou. (Writing) A state to another…. We do not think that graph A is correct because it [temperature] increases continuously, and […]

J: There's no time for the change.

At this point, Xunzhou proposed a counter-argument to their earlier argument which, in effect, was a kind of *self-rebuttal* of his prior argument (**A_G+R_S, Type 4B**) – an exceptional event.

X: By the way, I seem to have a small doubt about that. I may agree with him [Jiahou] a little…. Because…. if we put the ice in the incinerator, then there will be less time for it to change… its state. Because there is more energy supply. But it comes to a point when there is so much energy applied that the time was decreased to zero. Then there will be no time. There will be like absolutely no time for it to change states. So it's like a very immediate change of state, in [graph] A.

After discussing this his counter-argument, the students then discussed how they might rebut this counter-argument – a sequence of dialogue which was initiated by a question..

X: (Referring to the rebuttal section of the argument sheet) *If someone does not agree with us, then how would we convince him or her?*

R: So now we are saying that we are right....

X: That means we agree with B again…. My opinion is that because students don't have such equipment to produce such a high temperature for the water, so it is not quite possible for students to… produce something with so much heat energy that it could change state in less than a moment's time…. in just a short moment.... Also, the angle of the line will not be at such a […] uhm […]…. flat angle. And the line, if you use such an equipment… it will be at a steep angle.

Xunzhou argues, that if the ice were dropped into a container at an extremely high temperature such as an incinerator, graph A might be possible but the gradient of the line would be much steeper. Given that it was not, A was not a plausible answer suggesting that they have co-constructed not only the standard scientific explanation but also an understanding of why the wrong answer is wrong. Finally, the students completed the activity by translating their argument onto the argument diagram, which represented their ideas in graphic form.

Discussion and Conclusions

Evidence for Exploratory and Dialogic Talk

One of the aims of science education is the induction of students into a community of discourse or practice (Leach & Scott, 1995) that involves joint, explicit, and collaborative reasoning. In such a context, language is used as a tool for thinking and constructing arguments in students' quest for knowledge and understanding. In this study, students' questions were used to scaffold such discursive activity.

The data show that by thinking aloud and verbalizing their questions, the students made public what they were wondering about, allowing their peers to respond to and follow up on their ideas. By successively building onto each other's ideas and questions, the students co-constructed their arguments with each member contributing various component elements of the argument. The dialogue that revolved around these questions and arguments also made their thinking visible. Mercer, Wegerif, and Dawes (1999) defined such talk as "exploratory" in that "… partners engage critically but constructively with each other's ideas (p.97)" and where the students were, as Barnes and Todd (1977) put it, "each other's resource".

The students' talk in this study contained a number of elaborated explanations in response to challenge by a peer, including a clear articulation of the reasons underlying the thinking and relating evidence to theory (Duschl et al., 2007). There was also frequent use of some specific forms of language such as the "indicator words" associated with reasoning (Mercer, Dawes, Wegerif, & Sams, 2004). For example, the hypothetical nature of claims was preceded by "I think", "if", and "would"; and reasons were linked to claims by the use of the logical connectives "because", "so", "thus", and "since", which are conversational markers of dialectical thinking and reasoning. For instance:

- "*I think* that when it comes to the 100 ^{o}C point, it stays constant too *because* it's changing from liquid form to gaseous form."
- "*I think* that the energy supplied, after it changes from liquid state to gaseous state, *would* be used to increase the temperature."
- "We're saying that *if* the ice is at a very high temperature… it *would* actually cause it [ice] to melt right away."
- "Then the heat supplied must change its form or it must be used in some way. But *because* there is no more form to change, *so* the energy from the heat will be used to change the temperature of the gas…. *So* it will increase in temperature."
- "At the start of the experiment, it was ice. *So* the heat was used to break the ice into liquid form first. *So* there was no heat used to increase the temperature but most of it was used to change the form. *So* it must stay constant for the period when it was changing into liquid."

There were also a number of "if…then" statements, indicating the use of hypothetico-predictive argumentation (Lawson, 2003). Examples include:

- "*If* there is ice, *then* the ice must be at least at 0^{o}C."

- "[*If*] the ice is actually being thrown down into an incinerator, perhaps, *then* I think the answer will be graph A."
- "*If* we put the ice in the incinerator, *then* there will be less time for it to change… its state."

Students' explanations also contained a series of linked clauses and ideas, forming utterances that were sufficiently long to include multiple justifications in students' ideas and to show the progressive build-up in their thinking. Episodes representing oppositional thinking or rebuttals were also evident, characterized by words such as "but". For instance:

- "*But* I still support B…. Have you heard of super-heated steam that is over 100 ^{o}C?"
- "*But* at the end of the day, it [temperature] will be constant."
- "*But* then even if it changes to gaseous state, I still think that it should be boiling constantly rather than going up."

How Questions Influence Knowledge Construction and the Argumentative Process

Previous research has shown that in classroom settings where students were not encouraged to ask questions, teacher-dominated talk prevailed and there was a lack of dialogic or argumentative discourse (e.g. Alexander, 2005; Newton, Driver, & Osborne, 1999; Nystrand, Gamoran, Kachur, & Prendegarst, 1997). For example, Nystrand's large-scale study of American middle and high schools showed that classroom discourse was "overwhelming monologic. When teachers were not lecturing, students were either answering questions or completing seatwork. The teacher asked nearly all the questions, few questions were authentic, and few teachers followed up students' responses" (p.33).

On the contrary, in studies where students have worked in small groups and encouraged to question each other, the findings showed that the questions initiated sustained episodes of knowledge construction and argumentative discourse – similar to this study. For example, Hogan, Nastasi, and Pressley (1999) found that "an important element of sustained peer knowledge construction seemed to be the sharing of queries that served to articulate and clarify what the group did not know" (p.424). Likewise, Chin, Brown, and Bruce (2002), as well as Herrenkhol and Guerra (1998), found that questions embedded in the conversation of peer groups helped learners to co-construct knowledge, thereby engendering productive discussion.

The data from this study show that the questions that students posed helped them to note the given data in the graphs in some detail and to address any points of disagreement that they had. The questions directed the students' thinking, enabling them to share their prior knowledge, clarify points of uncertainty, as well as to generate and sustain dialogue through increasingly elaborate levels of argumentation. But why did this happen and, in particular, what was the role of the questions?

Our view is that students' questions acted as psychological tools or scaffolds helping the students to articulate their puzzlement through think-aloud verbalisation, and to structure the process and content of their thinking. The requirement to generate questions in phase 1 of the activity pushed the students to think about salient concepts required to understand the behaviour of water when heated. These "key inquiry" questions, which dealt with the substantive features of the scientific phenomenon at hand, particularly the causes and consequences, then became the foci of subsequent group talk and were revisited several times throughout the activity. In this way, they acted as springboards to further inquiry and dialogic talk by spawning further subordinate questions (such as those that addressed basic information, unknown or missing information, and conditions), which which activated critical cognitive engagement and the development of elaborated arguments.

In addition, the questions elicited answers, in the form of peer explanations and self-explanations, from the students themselves. In trying to answer their own questions, the students engaged in various forms of thinking – they described their observations, reasoned about causes and effects, formulated hypotheses, generated explanations, constructed arguments, justified their claims by recourse to evidence, questioned assumptions, identified unknown or missing information, critically examined competing explanations, evaluated each others' suggestions, challenged oppositional ideas, re-examined their initial ideas, made joint decisions, and summarized their ideas. Overall, students' questions led progressively to more sophisticated arguments.

Questions in these excerpts served a meta-cognitive function forcing student to think about their own thinking.. Indeed, Lawson (2003) has proposed that "more advanced reasoning begins when individuals ask questions, not of others, but of themselves" (p.1398). Through the "gradual internalization of the linguistic elements and the pattern of hypothetico-predictive argumentation", learners may develop the ability to "talk to themselves" and this allows them to "internally test alternative propositions... to arrive at internally reasoned decisions" (p.1398). In short, questioning (together with other cognitive processes such as explaining and hypothesizing) is central to initiating scientific reasoning and argumentation.

How Questions and Argumentation Promote Changes in Thinking

When students with opposing theories are put together to discuss their ideas in a group setting, contrasting world views are brought into contact. The resulting socio-cognitive conflict may help the students to decenter and become sensitive to alternative perspectives (Bell, Grossen,

& Perret-Clermont, 1985; Doise & Mugny, 1984; Mugny & Doise, 1978). In trying to resolve this conflict in their thinking, learners may then become dissatisfied with their initial conceptions and evaluate the intelligibility and plausibility of an opposing idea. If the alternative idea is found to be fruitful, this may then stimulate cognitive restructuring, engendering conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). Indeed, the study by Nussbaum and Sinatra (2003) found that “argumentation does have potential as a conceptual change intervention”, probably because “when constructing an argument, individuals must consider both sides of the issue, explain aspects of the problem that are anomalous to their existing conception, and must be confronted with the discrepancy between their point of view and the alternative” (p.393). Dunbar’s (1995) study of how scientists really reason led to the conclusion that “*Question answering was a potent mechanism to induce conceptual change* [italics added]… forcing the scientist to reorganize his or her knowledge” (p387).

But how, then, do students’ questions stimulate argumentative reasoning and help students to resolve their differences in ideas and perhaps engender conceptual change? Drawing on our data this question has led us to develop a model to explain how questions might stimulate argumentative reasoning .

A Model to Explain the Role of Students’ Questions in Supporting Argumentation

Figure 6 shows a model (referred to as QA to represent questions and answers elicited during the argumentation process) that attempts to explain how students’ questions may initiate and sustain argumentation during group discourse. It is based on patterns observed which were grounded in the data (Glaser & Strauss, 1967; Strauss, & Corbin, 1990). It describes a number of possible pathways involving self-explanations (Chi, de Leeuw, Chiu & Lavancher, 1994) and peer explanations that are mediated by questions posed to the self or to others. The model is based, in part, on the idea that one of the mechanisms responsible for the generation of questions stems from a need to correct declarative knowledge deficits (Graesser, Person, and Huber, 1992). Indeed, “questions are asked when individuals are confronted with obstacles to goals, anomalous events, contradictions, discrepancies, salient contrasts, obvious gaps in knowledge, expectation violations, and decisions that require discrimination among equally attractive alternatives” (Graesser and Olde, 2003, p.524). These questions may then mobilize different kinds of psychological processes that mediate argumentation and explanation. Such processes include construction (establishing internal connections among ideas) and integration (making links between prior ideas and incoming information).

[Insert Figure 6 about here]

In the QA model, a stimulus presented to students serves as a source of data. The stimulus could be in the form of a demonstration, a discrepant event, or a problem in textual or graphic form, just like in this study. This stimulus may also elicit alternative viewpoints and opposing ideas in students of how things work in the natural world. Observation of the data embedded in this stimulus may lead to a claim by the student of how and why things behave the way they do. This is a result of the student’s attempt to make sense of, and to explain, the given phenomenon. If the observation is as expected, this claim may be further elaborated by self-explanations and justifications to back up the claim. This pathway is depicted by the thin, solid lines (1).

On the other hand, if the observation is unexpected, this may stimulate cognitive conflict in the student. This puzzlement may then elicit a *self-question* posed by the individual to him/herself, which subsequently leads to a *self-explanation*. This second pathway is illustrated by the broken, dashed line (2). In the course of formulating this self-explanation, the student may encounter further puzzlement, which then generates another self-question and self-explanation. During this process, the student attempts to reconstruct his or her activated mental model to bring it into closer alignment with the given data. Research elsewhere (Chi, 2000; Chi, Bassock, Lewis, Reimann, & Glaser, 1989; Chi, de Leeuw, Chiu, & Vancher, 1994) has shown that the cognitive activity of self-explanation supports knowledge construction. Self-questions and self-explanations may be overt or covert, depending on whether they are externalized. However, it is important to note that for the student working in isolation – a form of individualisation encouraged by direct instruction – pathways 1 and 2 represent the only means by which new knowledge can be constructed.

Alternatively, instead of talking to him/herself, the student may verbally articulate the question to others, which would then elicit a *peer explanation*, as indicated by the bold, solid lines (3). When the student publicly makes a claim, this may also stimulate either agreement or disagreement among his or her peers. If this claim is accepted, other students may build on and add to the proposed idea – this is depicted by the thick line (4). However, if this claim is opposed, it could foster a sense of challenge in students with alternative viewpoints. This may result then in a rebuttal, which could be in the form of a counter-claim or a question, either of which may further elicit a peer explanation. This latter pathway is shown using dotted lines (5). The explanations constructed by the students during this group talk may be of varying quality and consist of one or more components of an argument, namely, data, evidence, warrant, backing, and qualifier. The interaction between the social and personal dimensions, mediated through questions, challenge, and explanations, reflects the movement between inter-psychological and intra-psychological planes. It also promotes reflexivity, integration, and the appropriation of knowledge.

In addition to pathways 1-5 where students' cognitive conflict, puzzlement, or claims are acted upon, it is also possible that they are ignored or not responded to. If this were the case, then there would be no further follow-up activity, resulting in no question asked, no explanation given, and no argument generated (pathway 6, dash dotted line). Such would be the reaction of the student for whom the phenomenon is not surprising or who does not even think it worthy of generating a claim. Likewise, if there is an opposition to a claim but this challenge is rejected, ignored, or not vocalised, there would also be no follow-up. This is depicted by pathway 7 (dash dotted line).

As Limon (2001) has pointed out, attempts to induce cognitive conflict and conceptual change, through the presentation of anomalous data or contradictory information, have led to controversial results. This may be attributed to several factors – such as students' motivation, epistemological and ontological beliefs, prior knowledge, values and attitudes, learning strategies and cognitive engagement, reasoning ability, and social factors – which influence whether the conflict is meaningful for the individual. Thus, for pathways 6 and 7 in the model, the presentation of conflicting information or a challenge may not elicit puzzlement, a counterclaim, or a rebuttal in some individuals. As Chinn and Brewer (1993, 1998) have postulated, there are various ways in which individuals respond to anomalous data: (a) ignoring, (b) rejecting, (c) professing uncertainty about the validity, (d) excluding, (e) holding them in abeyance, (f) reinterpreting, (g) accepting and making peripheral changes, and (h) accepting and changing theories. Table 5 gives examples from the data illustrating the different pathways described in the QA model.

[Insert Table 5 about here]

The QA model shows how students' questions support the articulation of evidence-based arguments. While pathways 2 and 5 illustrate the role that conflict plays in argumentation and reasoning through the process of accommodation, pathways 1, 3, and 4 are based more on the concept of assimilation where students' ideas become increasingly elaborate by adding to pre-existing concepts. This, in some respect, explains how both conflict and cooperation mediate the knowledge construction process. Furthermore, while pathway 2 depicts the role of cognitive conflict as an individual construct, pathway 5 shows how public discursive conflict may be resolved dialogically. Thus, the model accounts for both the personal and social construction of knowledge via questioning and argumentation.

More fundamentally, what the model offers is some insight into the limitations of direct instruction which is characterized by "teacher telling" and where students typically listen passively to the teacher's exposition. Such pedagogy restricts students' opportunities to develop their knowledge and understanding to pathways 1 and 2. Providing students the opportunity to engage in dialogic interaction about their ideas, either with their teacher or with their peers, increases the number of potential pathways through which conceptual understanding might be achieved. Our hypothesis, therefore, is that the use of such methods would enhance the pedagogic effectiveness explaining the results obtained by Zohar and Nemet (2002) and Mercer et al. (1999, 2004) – both of whom found that the use of a more discursive and argumentative pedagogy led to enhanced conceptual understanding. It would also explain why a knowledge of why the wrong answer is wrong – the kind of understanding demonstrated in the case we have examined here – leads to a more secure understanding of why the right answer is right (Hynd and Alverman, 1986). Students who lack such knowledge experience cognitive conflict (pathway 2) but often cannot generate self-explanations to refute what might appear the commonsense logic of informal scientific thinking. Students who have engaged in argumentation or questioning have had access to the conceptual resources of the community (pathways 3, 4 and 5) and the construction of a peer explanation which has then to be internalised as a self-explanation – an explanation which not only justifies the scientific view but which has assimilated the means of refuting alternative erroneous theories.

Critically, what the model also shows is how encouraging questioning is central to argumentation that leads to learning. Questions posed to others are both a self-recognition of puzzlement or uncertainty, the means of accessing the cognitive capital of the group or the teacher, and the initiator of counterclaims and peer explanations which ultimately leads to enhanced self-explanation.

The model would also explain other findings. For instance, Veerman (2003) found that argumentation supported by asynchronous computer-supported communications led to more constructive messages. Her hypothesis was that synchronous communications gave less time to "ask elaborated questions, express their doubts, or explain their problems" – a finding which suggests that the asking of questions and the construction of explanations is a core feature of developing student understanding. Hence, practice which specifically incorporates such elements offers more pathways to achieve the goal of student understanding.

It is also possible to make some testable predictions with such a model. If the process of questioning is central to argumentation as suggested, then training students to ask better questions of the phenomenon of interest, supplying them with relevant evidence, providing direct instruction about salient features, or offering them the opportunity to engage in research should lead to a higher quality of argumentation and conceptual outcomes. In contrast, merely engaging in argumentation alone can, at best, only raise the level of knowledge to that of the member of the group with the most advanced understanding – an argument which would explain the findings of von Aufschnaiter et al. (2008).

We recognize that the QA model is the product of a limited study in one context and thus tentative. However, the model could be tested experimentally providing a framework for future research.

Conclusion and Future Directions

There have been few micro-genetic studies of how argumentation and questioning function. Whilst the research presented here is the outcome solely an exploratory study, the results have, we believe, illuminated the potential for learning afforded by a pedagogy which combines both student questioning and argumentation. As a consequence, the results have led us to derive an explanatory model to represent the possible paths through which students may arrive at conceptual understanding by generating their own questions and explanations while being engaged in argumentative reasoning. According to this QA model, the presence of cognitive conflict, puzzlement, disagreement, and challenge could stimulate the generation of questions posed either to the self or others, and elicit arguments. In their absence, however, the number of pathways to constructing knowledge via self- and peer explanations is reduced since the student would then need to depend only on himself or herself to make sense of phenomena and to generate understanding (viz., pathways 1 & 2). But with only two routes, rather than five, to constructing knowledge by self-explanation and without input provided by others, a learner would find this more difficult to do. Since the model predicts that the inter-animation between different ideas through dialogic discourse opens up many more routes to conceptual understanding, then in the design of classroom instruction, teachers could include tasks that arouse cognitive conflict and puzzlement, and structure student-student discussions to involve disagreement and challenge.

In this exploratory study, the concepts and strategies associated with argumentation and questioning were introduced to the students only via a briefing. Yet, even with this short exposure, the study revealed that some students are capable of engaging in argumentation when appropriate scaffolds are in place. This study has shown not only effective ways that argumentation can be scaffolded but also provided a body of data which reveal how such a process supports conceptual change. The data invite the question of whether an extended programme that involves the explicit teaching of questioning and argumentation skills, together with multiple opportunities to practise in different contexts, would lead to more significant enhancement with argumentation and promote even deeper conceptual change. What this study suggests, however, is that the use of questions and the development of an argument are mutually symbiotic and interdependent, and that both activities are fundamental to productive discourse and scaffolding conceptual change.

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Table 1

Profile of Students Participating in the Study

Country	School	Class	Teacher	Class size	No. of groups
Singapore	S1	Year 7	ST1	39	7
	S2	Year 8	ST2	40	11
England	E1	Year 8	ET1	26	5
	E2	Year 9	ET2	24	6

Note:

Total number of students = 129

Total number of groups = 29

Table 2

Analytical Framework Used to Assess the Quality of Argumentation

Type of argument	Code	Description
1	A_C	A simple *claim* without justification or grounds versus another claim or counterclaim.
2	A_{G+}	One or more claim(s) with *simple* justification or *grounds* (comprising data, warrant, and/or qualifier and backing) but no rebuttal.
3	A_{G++}	One or more claim(s) with more *detailed* justification or grounds (comprising data, warrant, and/or qualifier and backing) but no rebuttal.
4A	A_G+R	One or more claim(s) with justification or grounds, and with a *rebuttal* that addresses a weakness of the opposing argument and/or provides further support for one's earlier argument.
4B	A_G+R_S	One or more claim(s) with justification or grounds, and with a *self-rebuttal* that considers the limitation or weakness of one's own argument.

Table 3

Types of Questions Asked by Students on the Question Web

Question type	Questions	School			
		S1	S2	E1	E2
Key inquiry					
Graph shape	What are the differences and similarities between the graphs?		*		✓
	Why is one [graph] wonkey and the other straight?			✓	
	Why is the graph (B) having a curved line from the point when it started increasing from 0 ^{o}C to the point it arrived at 100 ^{o}C?	✓	*	*	*
Flat portions	In graph B, why does the temperature remain at 0 ^{o}C and 100 ^{o}C for some time?	✓	*	*	*
	What is happening at 0 ^{o}C and 100 ^{o}C?	*	*	✓	*
Rate of temperature change	If the heat supply is constant, why is the change in temperature of the water not constant?		✓		
Why <0 ^{o}C	Why was the temperature of ice in the graph below 0 ^{o}C?	*	✓		
Why >100 ^{o}C	Why [does] the temperature keep rising [beyond 100 ^{o}C] although the boiling point is 100 ^{o}C?	✓	*		
Basic information					
Melting point / ice	What is the melting point of ice?	*			✓
	Does ice stay frozen for a certain period before melting?				✓
Boiling point / steam	What is the temperature of steam? Does steam have a maximum temperature?	*	✓		
	Is it possible for the water to exceed a temperature of 100 ^{o}C?	✓			
	Does water stop increasing in temperature after reaching boiling point?	✓			
Graph properties	Why isn't the X axis marked?	✓			
	What is the scale of the graph?		✓		
Particle theory	What are the particle differences between water, ice and steam?				✓
	Why do the bonds between particles need to be broken?		✓		
	Why is there no temperature change when the strong forces of attraction between particles are broken?		✓		
General	Under what circumstances does water go below 0 ^{o}C and go above 100 ^{o}C?		✓		
Unknown / Missing information					
Heating	Was the intensity of the heat fluctuating through the course of the experiment?		✓		
	Is the ice directly heated after it is taken out of the freezer or left out for a while?	✓			
Impurities	Is pure water used? Were any impurities [e.g. salt] added?	*	✓		*
	Was there an impurity in the water that caused the ice's temperature to be below 0 ^{o}C?		✓		
Surroundings	Are the conditions of the place where the water was boiled the same?	✓			
Room temperature	Is the room temperature constant?		✓		
Volume of ice	Was the volume of ice used for both experiments the same?		✓		
Surface area	How big is the surface area of the container in which the ice is melted?		✓		
Conditions					
Flame	Would the rate of melting/evaporating change if the intensity of the flame is adjusted?		✓		
	For graph A, is it possible that the flame was extremely strong so that the time taken to break the bonds was too fast to be recorded?		✓		
Room temperature	What would have happened if the room temperature had changed?		*		✓
Amount of ice	Would the graph be different if more ice was used?				✓
Time	What will happen if the water continues to be heated?		✓		

Table 3 (continued)

Types of Questions Asked by Students on the Question Web

Question type	Questions	School			
		S1	S2	E1	E2
Others					
Validity	Are the thermometers faulty?		✓		
Relevance	What evidence statement is relevant?			✓	
	How long does ice take to melt?		✓	*	*
	How long does it take to boil water?		*		✓

<u>Note</u>:

✓ Questions quoted directly

* Questions that addressed a similar idea

Table 4

Questions and Arguments Generated by the Four Groups During Group Discussion

Question type	No. of questions / arguments generated by Group			
	GE1	GE2	GS1	GS2
• Key inquiry	5	25	18	14
• Basic information	9	15	4	9
• Unknown / Missing information	0	0	7	0
• Conditions	1	0	5	2
• Others (viz., reference to argument structure)	0	19	32	10
Total no. of questions	15	59	66	35
Argument type				
• Type 1 (A_C)	1	1	1	0
• Type 2 (A_{G+})	5	9	4	2
• Type 3 (A_{G++})	0	4	3	6
• Type 4 (A_G+R or A_G+R_S)	0	5	5	3
Total no. of arguments	6	19	13	11

Table 5

Examples from Data Illustrating the Different Pathways in the QA model

Pathway	Example from data illustrating the pathway
1	Xunzhou, who claimed that graph B was more appropriate, posed the question “Why does the temperature of water stay constant at 100 ^{o}C before it increases some more?”. Subsequently, he generated a *self-explanation* by saying that the temperature was constant at 100 ^{o}C because the heat energy was used to change the water from liquid to gaseous state. He further explained that the temperature would remain at 100 ^{o}C only if steam were allowed to escape from an open pot. He also alluded to the formation of “super-saturated steam” if the pot containing the heated water was capped with a lid.
2	Sarah, who initially experienced *cognitive conflict* when shown the two graphs A and B, believed that neither was correct and drew an alternative graph C. She was *puzzled* by the plateau at 0 ^{o}C, as well as that at 100 ^{o}C. She asked “In graph B, in two certain parts, the temperature just stays constant.... Then it started increasing. I want to know why?”. Subsequently, she herself reasoned that the flat portion of the graph depicting “no temperature change” could be due to energy “being used to break bonds between particles” (*self-explanation*).
3	Following her self-explanation in pathway 2 above, Sarah also articulated her puzzlement to her group members about the plateau at 0 ^{o}C on the graph before the incline showing a temperature increase. To explain the slope after the initial plateau at 0 ^{o}C, Junhao suggested that “perhaps it has finished breaking its bonds between the particles”, this being an example of a *peer explanation*.
4	Xunzhou, who believed in graph B, accepted both Sarah’s explanation in pathway 2, as well as Junhao’s response to Sarah’s question in pathway 3 described above. He added that “the heat was used to break the ice to liquid form first”, to further account for the plateau at 0 ^{o}C (*peer explanation*).
5	Xunzhou claimed that graph B was the correct one which showed the temperature staying constant at 0 ^{o}C for a while. But Junhao initially disagreed with this idea, believing in counterclaim graph A instead. He posed a *challenge* to Xunzhou and *rebutted* by explaining that if the ice were thrown into an incinerator at a very high temperature of 300 ^{o}C, it would melt instantaneously and the temperature “will immediately shoot up.” Thus, in such as case, there would be no plateau at 0 ^{o}C depicted on the graph.
6	The cognitive conflict or puzzlement experienced by an individual is ignored or not acted upon, so it is not verbalized or made public. No utterance is manifested. Hence, there is *no further follow-up*. Likewise, if a claim made by an individual is ignored or not responded to, there is also no further follow-up.
7	If an individual disagrees with a peer’s claim but does not put up a challenge, the opposing viewpoint is not externalized. Alternatively, the disagreement may be simply dismissed or rejected. Both courses of action result in *no further follow-up*.

Figure 1. Task sheet on “Heating ice to steam”

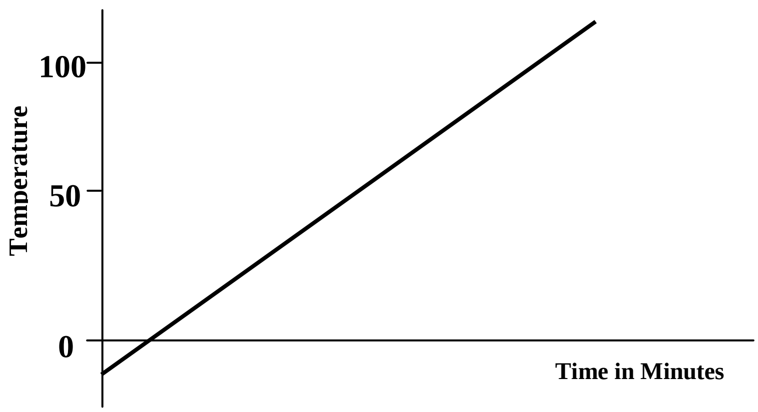
Heating Ice to Steam

Some students have been studying how water heats up.

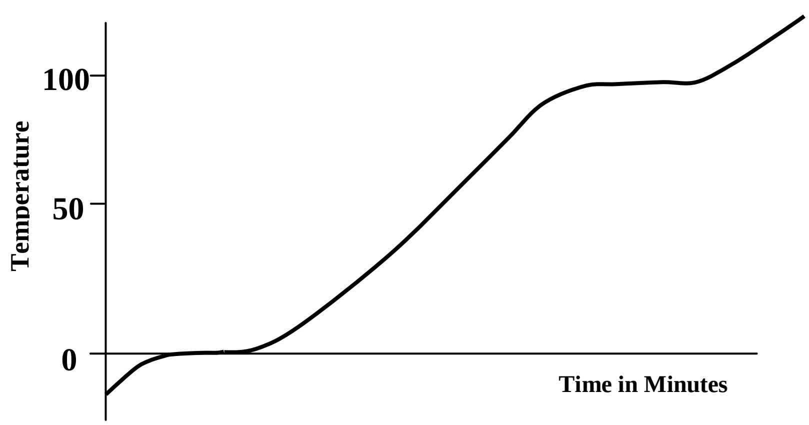
They had to predict the shape of the graph to show how the temperature would change as they heated ice to steam.

Below are two different graphs that they came up with.

a)



b)



In your groups discuss which graph is most likely to show how the temperature of water changes as it heats up. Your group must have at least ONE reason to support your argument.

Figure 2. List of evidence statements

Evidence Statements

Ice will melt when it is heated and turns into water

In solids there are bonds between the particles that hold them together in fixed shape

When you heat a substance the supply of heat energy is usually constant

Energy is needed to break bonds between particles

Ice melts at 0^{o} C and boils at 100^{o} C

Whilst energy is being used to break bonds between particles then there will be no temperature change

When substances are heated the particles in them absorb heat energy and move about more quickly

Figure 3. Question prompts given to students

HEATING ICE TO STEAM

<u>Questions for Students</u>
Use the following questions as a guide as you work through this activity. You do not have to ask or answer every question. Use only those that will help you to figure out your answer.

	Questions
Observing	• **What do I notice here?** - What changes are there (from the beginning, through the transitions, to the end)? - Is there an order / sequence in what happens? - Is there anything unusual or unexpected?
Comparing	• **What are the similarities and differences between A and B?** - How are A and B similar? - How are A and B different? - What is the significance of these similarities and differences?
Analysing	*Relationship between variables* • **What are the variables involved here?** • **What pattern or trend do I see here?** - What is the relationship between the variables?
Raising questions	• **What questions do I have about this?** - Is there anything that I am puzzled about? - What else would I like to know about …..?
Predicting	• **What would happen if …..?**
Explaining	• **What is my explanation for how this happens?** - Why does …..? - What are some possible reasons for …..? - How can I explain …..?
Justifying	• **What is the evidence to support my view?**
Evaluating	• **Which is the better graph? Why?** - Which evidence statement is relevant to my argument? • **Are there any exceptions or conditions under which this would not be true?**

Figure 4. "Our argument" sheet

OUR ARGUMENT

Problem / Question:
Which graph is most likely to show how the temperature of water changes as it heats up?

Our claim / belief	We think that the graph most likely to show how the temperature of water changes as it heats up is graph A / B (circle one) …..
Data / Evidence	Our evidence for this is …..
Reason	This evidence supports our idea because ….. We do not think that graph A / B (circle one) is correct because …..
Counter-argument	Someone might argue against our idea by saying that …..
Rebuttal	If someone does not agree with us, we would convince him / her by …..

Figure 5. Argument diagram

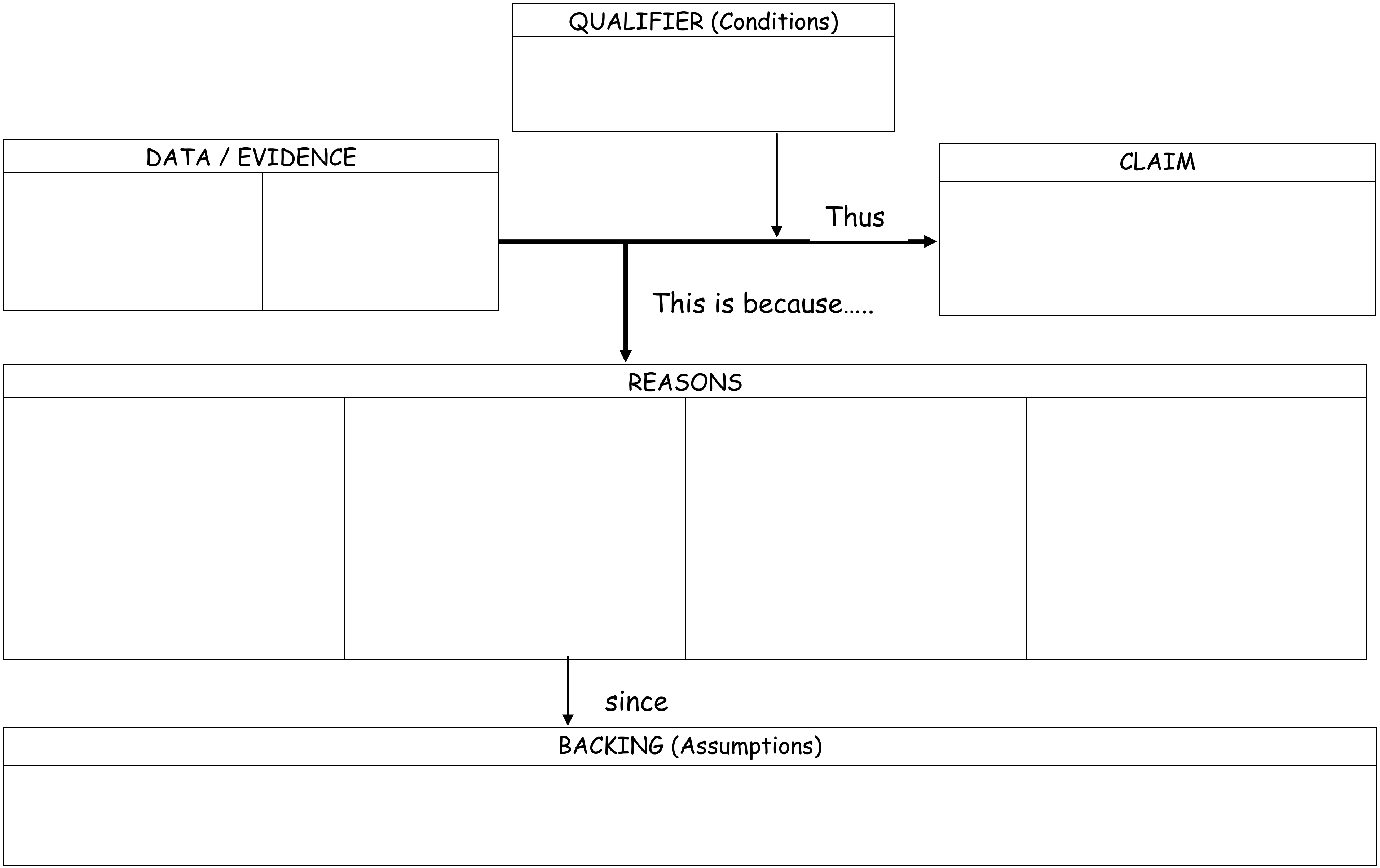


Figure 6. QA model showing the role of students' questions in supporting argumentation