THE SCIENCE CLASSROOM AS A SITE OF EPISTEMIC TALK:

TWO CASE STUDIES OF TEACHERS AND THEIR STUDENTS

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2012

ABSTRACT

Current science education documents emphasise both teaching the content and methods of science, and, promoting an understanding of the nature of scientific practices. One way of presenting the epistemic nature of science in the science classroom is foregrounding the role of argument in science. Argumentation is considered as a form of 'epistemic discourse' that can enhance students' epistemological understanding. Yet, little is known of the epistemic discourse initiated by teachers, either in ordinary or argumentation-based instruction. Therefore, this study explored the epistemic features of two science teachers' classroom talk, as they engaged in argumentation and non-argumentation lessons. The extent to which student discourse was influenced by teacher discourse during argument-based instruction, and students' views of theories and evidence, were also explored. An exploratory case study design was utilised. Teachers were observed teaching a Year 9 (13 lessons) and Year 10 (12 lessons) class throughout a school year. Other data collected included teacher interviews and field notes. One group of students from each class was also observed and interviewed. The analysis of classroom talk was based on 'epistemic operations'. The results showed how during argumentation lessons teachers engaged in the epistemic practices of construction, justification and evaluation. In non-argumentation lessons, classroom talk focused mainly on construction. The teachers' classroom talk depended on their views of the nature and function of argumentation, and their perceptions of students' difficulties with argumentation. The student talk modelled the teacher talk in the processes of justification and evaluation. Students engaged in epistemic discourse when they were confident of their knowledge of the topic discussed; the structure of the lesson was such that prompted them explicitly to engage in justificatory or evaluative processes, and, they were provided opportunities to discuss ideas in pairs before moving to larger groups. Implications for pre-service and in-service training that aim to promote argumentation in science education are discussed.

ACKNOWLEDGEMENTS

Firstly, I would like to acknowledge the great help and support I had from the two teachers that participated in this study. They were kind enough to listen to my requests and open enough to let me into their classrooms for a whole year. Without their willingness to improve their own teaching practices and embrace new ways of teaching and learning, this study would not be possible. I have learnt a great amount from them and would like to thank them for this. Also, I would like to thank all the students that accepted me as part of their classroom, were willing to talk to me for their interviews, and the interesting discussions we had about science and scientists.

Secondly, I would like to thank my two supervisors, Professors Jonathan Osborne and Peter Kutnick for their guidance throughout my studies. I would like to give a special thanks to Jonathan for giving me the chance to come to King's and work on the T2L project. Doing a research project in London was challenging but invaluable in my own development as a researcher. Thanks for being patient with me, teaching me how to structure and express my ideas, and of course, how to argue. I am still working on that. I would also like to thank Peter for taking me on after Jonathan left, and for teaching me that there is always a different perspective to each argument.

I would like to give special thanks to Dr. Maria Evagorou, who has been my friend, flatmate, colleague and advisor throughout my time at King's. She had to put up with a lot of complaining and worrying, but there were also many insightful conversations, she was always willing to listen, and for that I am grateful.

Other people I would like to thank is Professor Justin Dillon for his support, especially during my last year at King's; my Nvivo and G11 friend Emily Dawson; my London-based friends Ely, Ozy and Boris, and my cousin Dora, who all reminded me there's more to life than work. I would not be able to study and work in London without the support of my aunt Georgia and uncle Chris, who have always offered me their support and made me feel like home away from home. Also, my friends back home, who always believed in me, even when I didn't, and who remind me what being a teacher is all about every time I hear them talk about their students. Last but not least, I would like to thank my parents Costas and Eirini, who have supported me unconditionally with everything I have chosen to do in my life, even if that meant being away from them.

Finally, I would like to acknowledge the financial support I have received from the Rosalind Driver Research Scholarship Fund, which has supported my studies, my attendance at European and international conferences, and my participation at the ESERA Summer-School 2010. This study was also funded by the Economic Social Research Council, UK.

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SCIENTIFIC LITERACY, THE NATURE OF SCIENCE AND ARGUMENTATION: AN INTRODUCTION

Science education is considered as an integral part of the general education of young people. The importance of science education lies not only in the need to set the basis for the creation of future scientists but also for sustaining and improving the scientific literacy of the general population (DeBoer, 2000; Driver, Leach, Millar & Scott, 1996; Millar & Osborne, 1998; Roberts, 2006, 2011). Roberts (2006) discusses the distinction made within the science education community between literacy within science, which focuses on knowledge of the content and processes of the scientific practice (Vision I), and the ability required to apply such knowledge to science-related issues, essentially a focus on everyday applications of scientific knowledge (Vision II) in social contexts. Within this thesis, the term 'scientific literacy' is used to reflect both visions discussed by Roberts (2006) as both are part of current science education requirements.

Science – both as a practice and a product – is becoming an integral part of everyday life and therefore, the ability to understand and evaluate scientific findings critically is becoming a requirement of contemporary societies (Giere, 1991). Science courses offer students the opportunity to learn what the major scientific achievements of our time and of the past are, and understand the world in which they are living. What is more, science education should enable students to develop not only as individuals that are knowledgeable about science but also as citizens able to participate in their communities and engage with issues posed by science and technology within their everyday lives (Sadler, 2011; Roth & Burton, 2004; Osborne, 2010). In particular, Roth and Barton (2004) advocate that science education should be based on a model of 'citizen science' which is a 'form of science that relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday business' (p.9). This form of 'citizen science' would allow individuals to be critical and evaluative not only about the science they are learning but also about the processes and ideology of current scientific practices.

Furthermore, Osborne and Dillon (2008) in a review of the state of science education in Europe argue that students should be taught how to be 'critical consumers of scientific knowledge' (p.8) rather than unequivocally accepting anything they come across in scientific documents, texts or media reports. Similarly, a recent review from the National Research Council (NRC, 2011) at the United States maintains that science education should enable students to become 'careful consumers of scientific and technological information related to their everyday lives' (p.14). Such a view of science education would mean that students would be presented with opportunities to explore socio-scientific issues in the classroom and discuss issues of relevance to them as citizens of a modern technological and scientifically advanced society.

As a consequence of the demand that science education should form the basis of 'science for all' (AAAS, 1989) during the last two decades there has been a major shift in the goals of science education. Broadly, this shift in the nature of science curricula has been towards an education that offers students a more comprehensive picture of the scientific endeavour. That is, reform efforts in several countries in Europe, and at an international level, now acknowledge the need for students to develop an understanding of issues such as the importance of evidence in the practice of science, the cultural and social influences of scientists, and the strengths and limitations that scientific knowledge possesses, in addition to aims about conceptual understanding and practical work (Lederman, 2006). In fact, Donnelly (2004) and Donnelly and Ryder (2011) argue that the educational reforms of recent years in the UK have resulted in presenting science in a more humanistic light. 'Humanising' science education, they argue, requires students not only to understand the content of science but also to consider the ethical, societal and moral issues pertaining to science and society.

In addition, based on a humanistic perspective to science education it could be argued that asking students to memorise and understand only 'what we know' would be unjustifiable. Students also need to be provided with justifications for 'how we know what we know and why we choose to believe it over alternatives' (Duschl, 2008b, p.163). Thus, science educators also need to address the epistemic practices that characterise the scientific endeavour and explicitly aim to teach about the Nature of Science.

'Nature of Science' (NOS hereafter) refers to 'the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development' (Lederman, 2006, p.833). Through the NOS, the various aspects of the scientific endeavour are described, including aspects from the philosophy, history, sociology and psychology of science and the relationships that exist between these aspects, in order to explain what science is and how scientific knowledge is generated (McComas, Clough, & Almazroa, 1998). Accordingly, Millar and Osborne (1998), amongst others, recommend that science education for the future should include a consideration of the main 'ideas-about-science'. Such ideas are that explanations do not directly result from the empirical data available but also involve creativity and imagination, and that thoughts, ideas or explanations are influenced by the cultural background in which they were initially conceptualised.

A similar perspective to science education is taken in the current version of the National Curriculum for England and Wales (DfES). For instance, during Key Stage 4 (14-16 years old) students:

> 'learn about the way science and scientists work within society. They consider the relationships between data, evidence, theories and explanations, and develop their practical, problem-solving and enquiry skills, working individually and in groups. They evaluate enquiry methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision' (QCA, 2004, p.37).

Statements as the ones above, stress the importance of viewing science not only as a body of knowledge, but also as a way of critical thinking, which can advance students' ability to use logical reasoning, argument and to be critical of the knowledge they are presented with at school. Amongst the objectives for scientific literacy is the development of students' ability to 'evaluate the quality of scientific information on the basis of its source and the methods used to generate it' as well as the ability to 'pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately' (NRC, 1996, p.22). Moreover, Millar and Osborne (1998) argue that students should develop an understanding of science and become scientifically literate:

> ‘by considering the ways in which evidence and argument have been employed to establish reliable knowledge about the natural world, and by gaining experience in developing one’s own arguments, and in scrutinising those of others about natural phenomena, patterns and regularities in events, and possible explanations for them’ (Millar & Osborne, 1998, p.8).

The recommendations above by Millar and Osborne (1998) and those in national documents, stress the importance of a science education that moves ‘beyond processes’[1] and content (Millar & Driver, 1987). Duschl and Osborne (2002), for instance, maintain that changing the focus of science education towards one that goes beyond content requires a reconsideration of the role of scientific evidence within science, and science education. Students need to conceptualise the importance of evidence for the creation and establishment of explanations, and develop an understanding of the criteria utilised in constructing theories and explanations (Osborne, 2000).

The recommendations for science learning and instruction that encompass an explicit attention to the epistemic practices of science and at the same time, accomplish aims such as learning the concepts and methods of science, require the adoption of new instructional approaches that are able to achieve these goals. An approach to science learning and teaching that is able to place particular attention on both epistemic and conceptual aspects of science is argumentation (Driver, Newton & Osborne, 2000; Duschl, 2008a, 2008b; Kuhn, 1993; Sandoval & Millwood, 2008). As Duschl (2008b) suggests:

> ‘the how and the why focus requires adoption of dialogic discourse processes, of which argumentation is a part, in order to engage learners in the epistemic practices involving the selection of evidence for the development of scientific explanations’ (p.163).

Argumentation is an oral or written process of reasoning scientists go through to establish knowledge claims. Thus, as an approach to science teaching, argumentation places great

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[1] In this case, processes refer to the practical aspect of science and its methods. There is a distinction to be made between the term ‘process’ as practical skill and processes such as argumentation, which are based on reasoning skills. Within this thesis, the term processes is used in the second sense.

emphasis on the use of evidence for supporting or rejecting a theory, and does that through a more dialogic approach to learning (Driver, Newton & Osborne, 2000). It has been suggested that argumentation, and the epistemic discourse that surrounds argumentation activities, can promote students' understanding of the epistemology of science (Erduran & Jiménez-Aleixandre, 2008; Sandoval & Morrison, 2003). Yet, there is currently little research evidence to support this claim (McDonald, 2010). As McDonald (2010) points out in a recent review of studies that attempt to establish a connection between argumentation and an understanding of the NOS, in those studies that argumentation was taken up by students without explicit attention given to any NOS aspects, an improved understanding of NOS aspects was detected. According to McDonald (2010), this outcome would suggest that when argumentation is taught, explicit NOS instruction might not be as necessary for students to develop their NOS views.

Research on students' understanding of the NOS shows that students hold several misconceptions of the nature of scientific knowledge and practice (Driver et al., 1996; Lederman, 1992, 2006). In light of such results, educational researchers have suggested approaches to the teaching of science, which include an explicit introduction of students to aspects of the NOS within science lessons (Akerson & Volrich, 2006; Hodson, 1993) or through examples from the history of science (Abd-El-Khalick & Lederman, 2000; Solomon, 1994). The use of argumentation as a teaching approach for science is different from approaches implemented thus far to teach *about* science. Teaching science as argument does not include direct instruction of different epistemological aspects of science as the explicit approach to teaching about the NOS would suggest. Yet, teaching science as argument is not an implicit approach to teaching about the NOS either.

Argumentation activities place emphasis on the use of evidence to support or reject claims, on the evaluation of views and arguments and, the reasoning required during argument construction. What makes argumentation a different approach to the explicit inclusion of epistemological aspects of science in science instruction is that argumentation is an epistemic practice inherent to science, which aims to create justified knowledge. That is, through the use of argumentation as an instructional approach students are exposed and engaged in practices that require the epistemic justification for how we know what we know, how scientists use facts to construct knowledge, and how they develop the ability to evaluate claims based on evidence. Therefore, the utilisation of argumentation as a teaching strategy in science education can provide the grounds for exploring the epistemic features presented in a science classroom and the influence of argumentation as an epistemic activity within teachers' practices and students' epistemic understanding. Since argumentation is presented and modelled by teachers through language, the epistemic features of science teachers' classroom talk will be explored within this thesis. Moreover, as it will be discussed later on, this thesis was built as part of a larger professional development programme that aimed to promote dialogic argumentation into the everyday teaching practices of the participating teachers. This professional development programme provides the context in which the following research questions will be explored:

RQ1. What are the epistemic features of science teachers' classroom talk during argumentation and non-argumentation activities?

RQ2. Does science teachers' epistemic talk change as they participate in a professional development programme that aims to incorporate argumentation into their everyday practice?

To provide a comprehensive picture of the ways in which epistemic talk develops in the science classrooms investigated, the following questions that focus on students will also be explored in this thesis.

RQ3. What are students' understanding of the nature and role of theories and evidence in science, over the course of a school year?

RQ4. What are the epistemic features of students' talk during argumentation instruction over the course of a school year?

Examining students' views of the nature and role of theories and evidence in science is a way to determine the students' ability to engage in argumentation-based instruction, since their practical epistemologies or the ways in which they use evidence and theories in investigations will be evaluated. The epistemic features of students' talk are explored in order to identify any links between the teacher and student talk during the lessons investigated.

1.1 Thesis Overview

The teaching of science based on argumentation is the focus of this thesis. Specifically, the epistemic[2] nature of argumentation and the discourse produced during argument-based instruction are explored. Chapter 2 presents a review of argumentation, both through formal and informal argument, and discusses how and why argumentation has come to be considered a successful approach to science learning and teaching. In particular, the role of argumentation in (a) providing opportunities for the discussion of socio-scientific issues in the science classroom; (b) promoting scientific thinking and conceptual understanding and (c) engaging students with epistemic aspects of the scientific practices, will be discussed. As argumentation is a new approach to science instruction there is the need to create learning communities that promote and support this way of teaching and learning science. The role of the teacher in promoting and establishing argumentation in the science classroom, as well as their ability to do so, are discussed in Section 2.3. Professional development programmes that make use of such learning communities are one way of promoting change and learning in science education (Borko, 2004). This thesis is developed within the frame of a professional development programme, which aimed to help secondary school teachers incorporate argumentation into their everyday practices. The description of the 'Talking to Learn, Learning to Talk in Secondary Science' (T2L hereafter) project is provided in the last section of Chapter 2.

The epistemic nature of argumentation is discussed in Chapter 3, which presents a view of science as an epistemic practice, and argumentation as part of the epistemic practices that characterise science. The discussion of epistemic practices provides the basis for a consideration of epistemic discourse within science education. Argumentation is a discursive practice, a special kind of discourse, which aims to justify and evaluate knowledge claims. Therefore, argumentation is conceptualised as 'epistemic discourse' (Sandoval & Morrison, 2003), a way of talking science in the classroom, which carries an 'epistemic load'. This epistemic load is defined as the degree to which classroom

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[2] Within this study, the distinction between the terms *epistemic* and *epistemological* is based on that made by Hofer (2004) and Mason and Boldrin (2008), in studies of personal epistemology. In particular, the word '*epistemic'* is used to refer to the beliefs and assumptions guiding the nature of knowledge, and in particular scientific knowledge. 'Epistemological' on the other hand, is used to describe beliefs about the epistemology of science.

discourse represents and mirrors the epistemic practices of science and the processes that scientists go through to produce scientific knowledge. To examine the epistemic discourse of science classrooms, Section 3.3 provides a review of the literature that focuses on classroom talk and attempts to analyse its epistemic function. This review reveals that there is not much attention given to the epistemic discourse of science classrooms at the secondary school level, and especially to the talk that is initiated by the teacher. According to recent recommendations (NRC, 2007) the role of the teacher is fundamental in the development of epistemic discourse as 'students need support to learn appropriate norms and language for productive participation in the discourses of science' (p.186) since science teachers are the ones to introduce and model for students this different way of 'talking science' (Lemke, 1990).

Chapter 4 presents a review of the literature on students' formal and practical epistemologies of theories and evidence in science since the way in which students perceive the nature and role of theories and evidence in science may influence how students use theories, and how they reason about them. Consequently, these views might influence students' engagement with epistemic discourse in a positive or negative way.

The methodological considerations guiding this study are provided in Chapter 5. As will be discussed, a qualitative, exploratory case study design is considered as an appropriate research methodology for this study (Yin, 2003), as the T2L project provides a unique opportunity to examine in more detail the classroom talk of science teachers who attempt to incorporate argumentation into their everyday teaching practices. The methods of data collection, analysis procedures and ethical considerations are also provided.

Chapters 6 and 7 present the two case studies that were developed as part of this thesis. Case Study 1 presents a detailed account of the 13 lessons that James was observed teaching with his Year 9 group. Case Study 2 presents the teaching practices of Amy and her Year 10 class based on the 12 lesson observations conducted. Other data collected from teachers and students included semi-structured interviews and field notes. The classroom talk of the two teachers was analysed using the notion of 'epistemic operations' (Ohlsson, 1996), which were the discursive actions that the teachers engaged in when they talked to or with their students. In addition, the epistemic operations identified for each teacher were organised around the epistemic practices which they consist part of, namely, the construction, justification and evaluation of knowledge claims (Kelly, 2008, 2011). Each of Chapters 6 and 7 provides an analysis of first, the argumentation lessons observed, then, the non-argumentation lessons observed and finally, a comparison between the epistemic features identified in each of the two types of lessons.

Chapter 8 focused on the group of students observed as part of Case Study 1 and presents their views of the nature and role of theories and evidence and an analysis of their discursive interactions during the 6 argumentation lessons their teacher was observed teaching. This analysis aims to provide an insight to the epistemic discourse that students utilised during argumentation instruction and whether there were any links between the teacher and student talk during those lessons. Finally, Chapter 9 provides a discussion of the findings from the two case studies. It was found that argumentation as an instructional approach promoted the epistemic practice of evaluation in the teacher's talk. Moreover, the ways in which teachers utilised epistemic operations was context-specific and depended on their views of argumentation as an instructional approach and as a practice of science. The results from the student data showed how student talk paralleled that of their teacher's for the justificatory and evaluative practices. The implications for pre-service and in-service teacher training programmes that aim to promote argumentation as an approach to teaching and learning science are also discussed.

CHAPTER 2

ARGUMENTATION

2.1 ARGUMENT AND ARGUMENTATION

Reasoning in science is a thinking progression, which starts from what is already known, or what is assumed to be known, and follows a series of steps to a conclusion, whose validity is determined by the reasoning process followed (Harré, 1984). According to Longino (2002), reasoning has a twofold nature. Firstly, it is constructive since it can lead to the creation of new ideas or theories. Secondly, reasoning is justificatory, putting together thoughts and information as to provide support for an existing idea. The main objective of justificatory reasoning is 'not to reach new ideas but to establish the plausibility or likelihood of one already thought or articulated' (Longino, 2002, p.103). Argumentation is characterised by both constructive and justificatory reasoning, since through the process of argumentation new knowledge, which is justifiable, is constructed. The creation and justification of scientific knowledge is based on different types of argument that lead scientific investigations and advance scientists' understanding of the natural phenomena they are studying.

There are different definitions of argumentation; often associated with the function that argumentation has in different occasions. Within this thesis, argumentation 'is concerned with/dependent upon the *goodness*, the *normative status* or *epistemic forcefulness*, of candidate reasons for beliefs, judgment, and action' (Siegel, 1995, p.162, emphasis in original). That is, the main objective of an argumentative episode is to demonstrate why a claim, belief or statement is better than an opposing one. In this process, 'argumentation' is defined as the reasoning process individuals go through to construct an 'argument', which is the product. This argumentative process includes a constant consideration of evidence. Pieces of evidence need to be evaluated for their ability to provide support to a particular claim and the process of evaluation needs to be grounded on epistemic criteria. Argumentation, as a reasoning activity, includes instances of both formal and informal reasoning. The former is based on logical modes of reasoning (e.g. deduction) that are required to form valid conclusions. The latter is based on the reasoning processes individuals engage in everyday, informal contexts (Bricker & Bell, 2008). Both formal and informal reasoning processes are discussed in the next sections.

2.1.1 Formal Reasoning

Formal reasoning or logic in science can take the form of different ways of argument, such as deduction, induction or inference to the best explanation. Logical reasoning is based on the deduction of universal rules from a minor and a major premise, what Toulmin (2003) calls 'the Principle of Syllogism'. A major premise is more general or universal, such as a scientific law, whereas a minor premise is of a more particular nature, such as an empirical observation (Harré, 1984). Such a logical form of reasoning would be the following well-known example: *Socrates is a man; All men are mortal; thus, Socrates is mortal.* An important consequence of deductive reasoning is the truthfulness of the conclusion deduced from the premises, supposing these are true. Based on the assumption that the two statements presented in the example above are true, the conclusion that Socrates is mortal is an undeniable conclusion that can be used in further syllogistic reasoning. Moreover, the deductive form of argument provides grounds for prediction since based on a scientific law and a particular instance one is able to predict (or deduce) the outcome (Benton & Craib, 2001). The primary function of logic is of a justificatory nature during which the conclusion that one arrives at is justified through deductive argumentation. Consequently, logical reasoning could be seen as formal rules or laws of argument and argumentation as the process of constructing a case for one's claims or assertions and presenting them as scientific claims (Toulmin, 2003). This case should accordingly include the means of justification and proof through evidence, principles and laws used to support the claim advanced.

The Deductive-Nomological (D-N) model of reasoning developed and presented by Hempel (1965) would be an example of formal argument based on 'the principle of syllogism'. The D-N model defines scientific explanation of a phenomenon as the derivation of a statement from (a) facts and initial conditions of that phenomenon, and (b) general laws. Every explanation must be deduced from its particular conditions (the minor premise) and laws (the major premise), and these, must be true for the explanation to be valid. For instance, it is possible to reason that two objects with different masses, that fall from the same height, at the same time and with no other forces acted upon them, will reach the ground at the exact same time based on the law of gravity. Thus, falling can be explained based on the D-N model by providing the initial conditions that would justify the explanation given and the general law of gravity that supports the explanation.

An application of the D-N model of reasoning in the physical sciences is hypothetico-deductivism, which has a strong predictive character and is successfully used for hypothesis testing in the natural sciences (Hanson, 1971). According to hypothetico-deductivism, scientists conceive theories, which they then formulate into testable hypotheses. A hypothesis undergoes testing from which empirical consequences can be logically deduced. If the hypothesis is accepted, there is greater confidence to the validity and use of the theory created. However, if the experimental results contradict the predictions derived from the theory, then the theory is thought of as 'vulnerable' and 'possibly untrustworthy' (Hanson, 1971, p.62) and therefore, requires further investigation and testing.

The emphasis of hypothetico-deductivism is on the ways in which hypotheses are tested and empirical results are used as evidence for or against the principal theory explored. That is, the H-D model of creating explanations for phenomena presents the context in which these explanations are justified; the 'context of justification' of scientific knowledge. As a result, well-structured solutions are provided to scientific problems and questions about the consequences of particular premises, such as hypotheses, laws or theories, are posed (Hanson, 1971), which increase the validity and trustworthiness of the explanation under construction. Yet, hypothetico-deductivism is criticised for its inability to provide insightful information of the 'context of discovery', that is, the ways in which the initial hypotheses and theories are formed (Lipton, 2004). By ignoring the 'context of discovery' of scientific knowledge, the constructive nature of reasoning is put aside. The context of discovery provides the contextual framework in which knowledge is conceptualised and the norms (e.g. social, political) that have ruled this context of discovery. As a consequence, reasoning is not only rational but is also social (Longino, 2002) and can thus arise in informal and social settings.

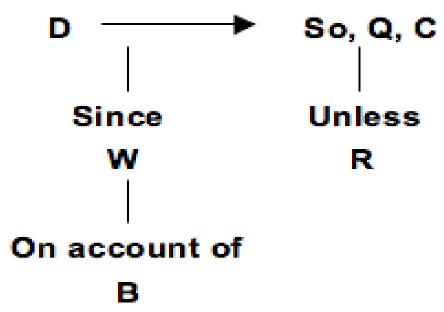
2.1.2 INFORMAL REASONING

Informal reasoning focuses predominantly on the reasoning that emerges in everyday situations (Kuhn, 1991) as opposed to the more formal modes of reasoning presented in Section 2.1.1. Arguments emerging from informal reasoning can be classified in two main categories. The first category includes rhetorical or monological arguments defined as justified assertions used to persuade others of the strength of a claim put forward by an individual. The second category includes dialogic or multivoiced arguments that are presented in the context of a dialogue with different perspectives examined, aiming to reach to a mutual understanding (Kuhn, 1991; Newton, Driver & Osborne, 1999). Within dialogic argumentation, the evaluation of a particular argument takes place by the other individuals participating in argumentation, and not just from the proponent of the argument, as in rhetorical argumentation (Walton, 1996). Each of the participants of this dialogic exchange is initially attempting to justify his/her own belief and subsequently or simultaneously, to rebut the opposing view producing counter-arguments (Kuhn, 1991). Consequently, dialogic argumentation requires an explicit attention to the production of counter-arguments and the ability to consider alternative perspectives and negotiate meaning while arguing.

Toulmin's book *The Uses of Argument*, first published in 1958, has been influential in the field of argumentation theory, especially on the utilisation of argument as informal reasoning. Toulmin (1958/2003) focuses on how logic is applied in practice to resolve 'conflicts of mind' and develop rational arguments. Reflecting on the justificatory nature of logic and its practice through argument, Toulmin (2003) stresses the importance of proof for the establishment of an argument. He asserts that the strength of such proof relies both on the quality of the sets of evidence that accompany the argument as well as on the warrants that support the evidence. Holding in mind such considerations about logic, proof and the role of evidence in reasoning, Toulmin addresses the fundamental question of how one is actually to assess the soundness of the arguments produced in an everyday context. Each argument is different depending on the topic discussed and the participants' points of view. Yet, all arguments have some common features that could be used as guideposts for the creation and evaluation of arguments. These 'field-invariant' characteristics of arguments are those that determine the strength of a conclusion, like the inclusion or not of warrants to support the evidence for a claim put forward. Accordingly, it is possible to assess the soundness of arguments produced in informal contexts on the basis of criteria such as how evidence is used and supported in an argument and whether claims can be rebutted.

The framework that Toulmin (2003) proposes for the evaluation of arguments consists of six key concepts (Figure 2.1), all of which have an important role to play in the creation of a sound argument.

Figure 2.1: Toulmin's analytic framework of argument



Based on the definition of an argument as a justified assertion one first needs to provide the assertion or claim and then attempt to justify his/her belief in this claim with the appropriate grounds of evidence. The way to do this is by providing the appropriate data (D) on which the claim or conclusion (C) is based. Yet, the way in which the particular evidence has been used to justify the conclusion must also be made explicit. In other words, one needs to demonstrate how s/he has come to the particular conclusion. The process of arriving at a conclusion is achieved by providing the appropriate propositions (e.g. rules, principles) which Toulmin calls warrants (W). These propositions 'can act as bridges and authorise the sort of step to which our particular argument commits us' (Toulmin, 2003, p.91) and are essentially the grounds of belief that transform pieces of data into relevant evidence for a claim. Warrants are of different types and the power of justification they may carry varies. For instance, a warrant may 'necessarily' lead one to a conclusion bearing a strong degree of force on it. In other cases, a warrant may 'presumably' or 'probably' lead to a conclusion, in which case its degree of force on the conclusion will need to be qualified. Therefore, a qualifier (Q) and/or a rebuttal (R) may be needed. A qualifier indicates the strength that a warrant has in qualifying a set of data as supportive evidence for a particular conclusion while a rebuttal constitutes those conditions in which the general authority of the warrant must be set aside. This form of argument may be sufficient to support a conclusion, assuming that the warrant provided is accepted or the justification is based on the warrants' authority. Nevertheless, there are instances in which this warrant must be backed up to assure further that the conclusion is legitimate, thus creating the need to provide a backing (B) for the warrant.

The framework provided by Toulmin (2003) has been widely used to assess the quality of argumentation in different settings. Yet, several criticisms exist. Toulmin himself, commenting on his framework states that it does not always provide particular ways in which premises can be used as warrants or rebuttals of a claim. Moreover, there is often difficulty in distinguishing data from warrants that can be used as evidence to support a claim (Driver, Newton & Osborne, 2000) or warrants from backings (Andrews, 2005). Accordingly, Sampson and Clark (2006) maintain that the emphasis placed on the field-invariant characteristics of an argument has resulted in inadequate information for the field-dependent criteria of what makes a good argument. These problematic issues are grounded in the fact that Toulmin provides a generic model for argument that, whilst its application may result in the creation of a strong argument, it is not always easy to apply in different disciplines or topics. Simplicity 'has its perils' (Toulmin, 2003, p.133) and therefore, the analysis and evaluation of arguments should also take into account the context in which an argument is established. For instance, the kind of argumentation that is most likely to be present in a science classroom is dialogic argumentation and therefore, factors such as the ways that social interaction and group dynamics may influence the quality of the argument need to be considered (Clark, Sampson, Weinberger, & Erkens, 2007; Kelly, 2008; Newton, Driver & Osborne, 1999).

Another framework of argumentation implemented in the teaching and learning of science (Duschl, 2008b) is that provided by Walton (1996), who considers argumentation as 'presumptive reasoning', a form of argument prevalent within informal reasoning. This framework takes into consideration the content of the argument, in addition to its general characteristics, an aspect that Toulmin's framework fails to take into account. According to Walton (1996), what characterises dialogic argumentation is that a particular argument is always considered in terms of the context in which it is produced and not its abstract form (formal reasoning). Moreover, the argumentation process is influenced both by the proponent and respondent of the argument since, depending on who you are arguing with/against, one may or may not make certain information explicit in their argument.

The framework Walton (1996) proposes is comprised of 25 different argumentation schemes in which argument may occur. These argumentative schemes are accompanied by a set of critical questions utilised in assessing the quality of an argument. An argumentation scheme is the structure that a particular argument takes within a dialogue and which forms a way of reasoning dependent on the situation. Walton maintains that the 25 argumentation schemes he proposes are mainly rhetorical or persuasive rather than logical. That is, the argument presented is not evaluated as much for its logical coherence as for its persuasive nature. The aim is to persuade the other person rather that to present him/her with a logically compelling argument. This is because dialogic arguments are often based on presumption and plausibility, since the proponent of an argument may not have genuine or 'hard' evidence to support his/her argument. Thus, presumption of adequacy is utilised as the means to support an argument when evidence is absent. For instance, one of the argumentation schemes that Walton (1996) proposes is the 'argument from position to know' scheme in which the proponent of the argument is considered to hold an authoritative position towards the respondent due to his/her presumed higher level of knowledge. Thus, if the proponent makes an assertion and the respondent knows that the proponent is in a position to have some reliable knowledge about his/her assertion, the assertion is accepted. In this case, the respondent of the argument is called to infer and critically consider whether the proponent of the argument really has some knowledge about the issue under discussion.

On the whole, Walton's framework of argumentation accounts for issues that the Toulmin framework does not, such as the context and the participants in which argumentation takes place. Nonetheless, Walton's argumentation framework consists of 25 different cases that could be applied in argument construction, which makes its application in the science classroom more difficult to achieve. What is more, reasoning modes as the one presented through the example provided of the 'argument from position to know' scheme, does not contribute towards the explication of the reasoning process by students. As will be further discussed in the following sections, one of the aims of teaching and learning science through argument is to help students develop their thinking skills by utilising evidence in their discussions and explicitly sharing their reasoning within their groups.

Therefore, the Toulmin framework, which requires the inclusion of a claim and also the evidence and warrants that support the claim in order to construct an argument, is a better way to structure arguments in the science classroom. The simplicity of Toulmin's analytical framework is one of its main advantages. The use of a generic model of argument, such as Toulmin's, is valuable for assessment and evaluation purposes since science teachers can apply this model to assess their students' oral and written arguments. Finally, it can be used to compare arguments in different subjects since individuals will be following the same principles for creating and establishing their arguments.

Overall, argumentation is a reasoning activity that can be applied in scientific contexts in the form of logical reasoning and in everyday contexts, in the form of informal reasoning. The particular ways in which argumentation is practiced as instances of informal reasoning are of interest to the aims of this thesis, since argumentation is advocated as an approach to science teaching and learning (Diver, Newton & Osborne, 2000; Erduran & Jiménez-Aleixandre, 2008). Thus, the next section presents research evidence of people's ability to argue in order to determine whether argumentation could be successfully practised by students.

2.1.3 Research on People's Ability to Argue

Informal reasoning is a process that takes place in everyday settings and that forms people's ability to argue. A major source of research evidence on people's ability to use informal reasoning and construct arguments is Kuhn's (1991) work on argumentation and thinking skills. Kuhn's study focuses on people's ability to construct rhetorical arguments on three distinct everyday-life issues. Specifically, 160 participants of four age groups (teenagers–14 to 15 year-olds, 20s, 40s and 60s), of different educational backgrounds (college and non-college) and of equal gender representation were interviewed to elicit their beliefs on the subjects of school failure, unemployment and prisoners returning to crime, and to explore the ways in which participants supported their beliefs. Subjects were first asked to provide a causal theory for each topic and then to suggest any evidence that would show the correctness of their theory. They were subsequently asked to consider what would be the possible opposing views to their own causal theories, prompted to provide alternative theories and evidence to support the counter-arguments.

Finally, participants were asked to rebut the alternative theories by asking them 'What would you say to show that this other person is wrong?' to think of ways to reject the alternative theories.

Using Toulmin's analytic framework of argumentation, Kuhn was able to assess the participants' causal theories in terms of the quality of evidence, counter-arguments and rebuttals provided. Kuhn concluded that participants were not in a position to understand the strength of the evidence they provided, with most of them giving 'pseudo-evidence', which were described as examples and/or restatements of the participants' causal theories instead of information that directly provided evidential support for their causal theories. The dominance of pseudo-evidence among the participants showed an inability to distinguish between strong and weak evidence and their effect on the causal theories. The participants most able to provide direct evidence for their explanations seemed to be able to understand and conceptualise the nature and function of evidence in argumentation and more importantly, they were also more likely to provide alternative theories for their explanations. The participants' ability to construct counter-arguments was considered by Kuhn as indicative of a higher reasoning ability since individuals were required not only to support their position with warranted evidence but also to consider counter-positions and provide evidential support for them. An even more demanding reasoning task, according to Kuhn, was the generation of rebuttals for the alternative theories since it required individuals to compare the initial explanations to the alternative ones and make evaluative judgements for their correctness.

The findings emerging from Kuhn's study about people's inability to consistently use evidence to support their theories have been contradicted by studies that show that even young children have the ability to coordinate causal theories and experimental results when they are sufficiently supported and guided (Koslowski, 1996; Koslowski, Marasina, Chelenza & Dublin, 2008; Samarapungavan, 1992; Sodian, Zaitchik, & Carey, 1991). Koslowski et al. (2008) provide evidential support to the claim that individuals are able to reason and provide evidence-based explanations when given the appropriate support. For example, participants of their study were supported through prompts such as being reminded of the explanation investigated and the background information of the topic discussed in order to provide the participants with the appropriate theoretical background that would help them consider information as evidence for an explanation. Furthermore, Carey (1988) claims that the fundamental disparity between young children and adults is the amount of domain-specific knowledge adults have that establishes them as higher-order thinkers. Young students possess essentially less content knowledge than adults and are considered as novices that have greater difficulty in interpreting information. More recently, Kuhn (2009) maintains that argument 'by no means "comes naturally", despite its roots in everyday conversation and [thus] requires sustained engagement and support' (p.5). Hence, young people need to be introduced into this way of thinking and science education should provide opportunities for them to review information, evaluate positions and consider anomalous data in order to coordinate theory and evidence and move towards the scientific ways of thinking. What is more, the role of the teacher is fundamental in attempts to advance students' reasoning abilities within science education since it is the teacher that will provide the necessary support needed for students to develop their reasoning and thinking skills.

The research conducted by Kuhn (1991) has had a major influence in the way in which argumentation as informal reasoning can be applied in science education to help young people develop their reasoning skills and become higher-order thinkers. The fact that Kuhn's (1991) results show that there was no substantial difference between the 16-year-olds taking part in her study and the older participants, suggests that students at this level need to engage systematically in activities that can develop their ability to reason and construct arguments. Therefore, within this thesis, particular interest is placed on the secondary school level and research that focuses on enhancing secondary school students' argumentation skills and understanding of the NOS is presented. As discussed in Chapter 1, there are now a number of policy documents that stress the important of argumentation for the learning of science at the secondary school level. The next section presents attempts to incorporate argumentation in science education supporting the view that it can help advance students' learning of, and about, science.

2.2 Argumentation and Science Education

In the last two decades, there has been increasing interest in the way that argument can be utilised in science education (Driver, Newton & Osborne, 2000; Erduran & Jiménez-Aleixandre, 2008). Kuhn (1993) makes the case for considering science education as argument, since this perspective on learning and teaching science can be beneficial for both students and teachers. In particular, the following sections, will discuss the benefits that argumentation might have on students' development of scientific literacy, conceptual understanding and epistemological understanding.

2.2.1 Argumentation for Scientific Literacy: discussing and learning from socio-scientific issues

Argumentation is considered an approach to science learning and instruction that can contribute towards scientific literacy and the public understanding of science (Cavagnetto, 2010; Driver, Newton & Osborne, 2000; Duschl & Osborne, 2002; Erduran & Jiménez-Aleixandre, 2008). As discussed in the first chapter of this thesis, the term 'scientific literacy' is used to describe both the ability to engage in critical evaluation and discussions about scientific issues as these present themselves in everyday life – that is, the derived sense – and in its fundamental sense that is the ability to understand of scientific text (Roberts, 2006, 2011).

One way that argumentation contributes to scientific literacy is through studies which investigate students' understanding of, and engagement with, socio-scientific issues. Socio-scientific issues (SSI hereafter) invoke different views and often set the basis for argumentation. For the purpose of this thesis, SSI are defined as:

> 'controversial issues on which competing views are held by different parties and which have implications in one or more of the following fields: biology, sociology, ethics, politics, economics and the environment. The controversial nature of socio-scientific issues is related to the degree of uncertainty involved in many issues' (Simonneaux, 2008, p.179).

The characteristic of SSI that makes them suitable as a context in which argumentation activities can be planned and carried out, is that they carry a degree of controversy that creates differing views students can discuss and argue about. Simonneaux (2008) continues by stating that the consideration of SSI in educational settings is able:

> 'to improve knowledge understanding, to contribute to citizenship education, to help students to make informed decisions, to empower them to participate

> in debates, to help them to be able to deal with complexity, and to understand better the NOS' (p.181).

Thus, the educational applications of argumentation and SSI fit well with the main characteristics of curricula such as Twenty First Century Science in the UK, which now focus on inquiry; citizenship and ethics; and, science and the workplace and incorporate exploration of SSI (Donnelly & Ryder, 2011). Through dialogue and evidence-based discussions students are provided with opportunities to engage with ill-structured problems or 'socially acute questions' (Simonneaux, 2008) about ethical and societal issues related to science such as global warming, gene therapy etc., evaluate a situation and reach conclusions. In this way, students can develop a sense of 'collective responsibility' and 'social consciousness' that allows them to consider issues that overlap between society and science and that are of relevance to them or the communities of which they are part (Roth & Burton, 2004). Consequently, arguing in the context of SSI within science education is a way to humanise science for the students (Aikenhead, 2006; Donnelly, 2004; Donnelly & Ryder, 2011; Zeidler & Sadler, 2008).

An example of a study that provides evidence of the positive influence of argument-based activities relating to SSI to students' understanding of science and their development of argumentation skills is presented by Zohar and Nemet (2002). These authors devised an instructional unit which included 10 moral dilemmas about human genetics that two classes of 9th graders discussed over a period of 12 lessons. The participants of this study also received explicit instruction on constructing arguments. Comparisons between the intervention and a control group (who did not discuss the dilemmas) of the amount of content knowledge that students used to discuss the same dilemma (cystic fibrosis) at the start and end of the study, showed statistically significant differences in the post-test in terms of (a) the frequency of students that made use of relevant content knowledge, which was higher for the intervention group; (b) the frequency of students that used content knowledge correctly which was also higher in the intervention group; and, (c) the higher frequency with which students in the control group made unsuccessful attempts to make use of appropriate content knowledge. Students' argumentation skills were also assessed through their written work and audiotaped discussions of two groups of students. The results indicate that although students were able to form simple arguments, counter-arguments and provide rebuttals at the start of the study, their ability to do so at the end of the study had increased, as demonstrated through the increased use of justifications and explicit conclusions made.

Zohar and Nemet's (2002) study demonstrates how SSI can be used to contextualise scientific content and enable students to use that content to support their arguments about specific SSI. A point discussed by the authors of this study is that the participating students, in addition to the instruction on argument construction they received, were also instructed explicitly on the differences between values and knowledge, which can be used as evidence in support of claims. Specifically, Zohar and Nemet (2002) state that 'values are not determined by knowledge; although all students share the same knowledge base, each may make his or her own independent value decisions' (p.40). As a consequence, during argumentation about SSI, students are not only required to base their discussions on empirical evidence, but are also requested to draw *normative* criteria of moral/ethical principles and values (Kolstø & Ratcliffe, 2008; Sadler, 2011; Zeidler & Sadler, 2008). Rational individuals in normative or moral contexts could be characterised as those who 'act judiciously, that is, neither give in to their affects nor pursue their immediate interests but are concerned to judge the dispute from a moral point of view and to settle it in a consensual manner' (Habermas, 1984, p.19). In fact, Grace and Ratcliffe (2002) who studied English 15-16 year-old students' discussions about two biology conservation issues, found that students' discussions were dominated by considerations based on ethical and economic values rather than scientific concepts such as food chains, species, competition and extinction, although the students were able to consider both forms of justifications to support their views (content-based and value-based). Therefore, in the case of SSI, critical thinking draws on the use of values as a form of justification and not just on empirical data or evidence.

Thus, the discussion of SSI require students to make evaluative judgments of the differing views presented, consider the normative and empirical evidence or grounds for belief and in this way, reach to an informed decision. For instance, students discussing embryo selection would be expected to argue within their value systems and state not only if they think that embryo selection is right or not, but also *why* based on the value systems of their society and empirical data they might have. At the same time, students would also need to consider cases in which embryo selection would (not) be acceptable, and would also need to attempt to explain why their argument is better than opposing views by providing rebuttals and constructing counter-arguments. Thus, the way that students would need to structure their arguments in a socio-scientific context is similar to the ways students would be required to argue within a scientific context in that the elements of Toulmin's model are alike, although the nature of the evidence used would vary. In the case of scientific controversies, the resolution of arguments is dependent on the use of normative scientific criteria of what constitutes good evidence. In contrast, when discussing SSI rational consideration of the topic does not necessarily demand students to change their views, as this would possibly require a change into a new belief system (e.g. if they are against embryo selection due to religious beliefs). Both forms of argument however would require students to justify their position and take an evaluative stance to what is presented to them.

2.2.2 Argumentation, Dialogic Engagement and Conceptual Understanding

Another reason for supporting the implementation of argumentation in science education is its dialogic nature, which has been shown to have a positive influence on students' conceptual learning. Socio-cultural perspectives on learning and instruction, based on the work of Vygotsky (1978), place language and dialogue in the core of teaching and learning activities. Moreover, Alexander (2005) emphasises the interrelationship of language, thinking and knowing and supports the view that effective learning is the result of successful links between these three constructs. Consequently, classroom talk should challenge and develop students' reasoning. Dialogic argumentation can take place in social settings, such as classrooms, providing students with opportunities to engage in dialogic processes and learn through arguing (Andriessen, 2005). The advantage that reasoning through dialogic argumentation has is that it facilitates students' engagement in critical reflective processes of what they know and what they think they know. In this way, students are presented with opportunities for reflection on their own knowledge and learning and create the cognitive conflict necessary for the development of conceptual understanding (Limón, 2001).

Mercer, Dawes, Wegerif and Sams (2004) report how discursive activities can be useful in scaffolding the development of reasoning, even in younger age groups than the ones mentioned by Kuhn (1991). The participants of the Mercer et al. (2004) study, who were

9-10 years old, engaged in activities designed to help them develop specific talking skills using ‘exploratory talk’. As the authors assert, the explicit teaching of how to use language constructively in the classroom, is a necessary, yet rare, practice amongst science teachers. Teachers need to explicitly model constructive ways of talking, through their own talk and through the activities they prepare for their students. ‘Exploratory talk’ is such a way of modelling and was used by the researchers as an effective way of talking in the classroom during this study. Such talk shares the same principles with argumentation-based instruction where the teacher attempts to encourage students to justify their answers through ‘how and why’ questions and build on their ideas to construct their arguments. The qualitative and quantitative data gathered from the intervention and the control groups demonstrated the positive effect that exploratory talk had on pupils’ thinking skills and on their attainment in science. Students, using language, managed to develop reasoning skills and do better in the science activities they were engaged in, compared to the control groups that were not taught how to use exploratory talk.

Venville and Dawson (2010) provide empirical evidence to support the assertion that argumentation-based instruction enhances conceptual understanding. They designed an experimental study to investigate the effect of short-term argumentation instruction on secondary school students’ argumentation skills, informal reasoning and conceptual understanding of socio-scientific issues on genetics. Their intervention consisted of three argumentation lessons (one teaching and modelling argumentation skills based on Toulmin’s framework and two on the topic explored using whole-class discussions) taught to two classes of Grade 10 students. The argumentation lessons were taught by the same teacher, who had previously received training in using argumentation. Two other classes of Grade 10 students with a different teacher functioned as the control group. The authors report that students in the argumentation group demonstrated improvement in their argumentation skills, informal reasoning improvement and a statistically significant increase on their content knowledge of genetics. Similar results are reported by Cross, Taasoobshirazi, Hendricks and Hickey (2008), who also explored Grade 10 students’ engagement with argumentation in a biology topic using specialised software, which was designed to promote discursive and collaborative engagement. These researchers also report that there was an improvement from pre- to post-testing of students’ conceptual understanding of the topics investigated.

Another report that provides evidence for the positive influence dialogic argumentation can have on learning science, is provided by Nussbaum and Sinatra (2003), who examined whether students' engagement with argumentative activities would facilitate conceptual change in the subject of science. Their research asked 41 undergraduate students with no specialised knowledge in physics to construct an argument to explain a particular phenomenon in physics. The participants were asked to go through three computer simulations individually explaining similar problems, try to give a prediction, and finally, develop an oral and written argument to explain their predictions. After this task, participants were categorised randomly into a control and an experimental group. The participants comprising the experimental group that provided an incorrect answer to each of the three simulations were further prompted to argue the opposite view and reconsider their answers before shown the correct answer. By encouraging students in the experimental group to argue the opposite view, students provided the conceptually correct answer in a higher percentage than students in the control group, in addition to providing significantly better reasoning. Moreover, when students from the experimental group were tested after a period of time to see if this conceptual development was sustained, the results were positive indicating that dialogic argumentation may support mastery learning and the long-term enhancement of students' conceptual understanding.

2.2.3 Argumentation and Epistemological Understanding

The epistemic nature of argumentation also supports the inclusion of the use of argument in science education. Argumentation is a core element of the practice of science. Within a scientific community, scientists need to constantly negotiate meanings, consider alternative and competing theories and communicate their results in convincing ways. In this respect, argumentation is 'a genre of discourse central to doing science' (Duschl & Osborne, 2002, p.52). Science education programmes, which aim to promote an understanding of all the facets of the scientific endeavour – and not only of its final product – should aim to develop skills and 'habits of mind' (AAAS, 1989) parallel to those of scientists. By engaging students in the kinds of discourse scientists engage in, students are in a position to understand the steps that claims go through in order to be established as knowledge. As a consequence, students have the opportunity to appreciate the rationality underlying the scientific practice, as well as the strengths and limitations of the knowledge produced (Millar & Osborne, 1998). Hence, a view of argumentation as an epistemic activity further supports the view that science teaching should be developed within an argument-based framework. The practice of argumentation may engage students in the epistemic process of knowledge production and evaluation, which requires the use of criteria for the selection of evidence and evaluation of claims and evidence, persuasion of other members of a group or a class of students and the creation of counter-arguments. These actions depend on the way that teachers will organise and implement argumentation activities as part of their teaching practices, and thus, the role of the teacher in argument-based instruction needs to be considered.

2.3 Teaching Science as Argument: the Role of the Teacher

The different ways argumentation can be of value to science education, presented in Sections 2.2.1-3, have encouraged the educational research community to pay special attention to argument, and to the teacher's role in promoting elements of argumentation in science classrooms (Driver, Newton & Osborne, 2000; Erduran & Jiménez-Aleixandre, 2008; Zembal-Saul, 2009). Making argumentation a feature of science education generates many questions – some of which are the focus of this thesis. Any attempts to teach science as argument need to be accompanied by sustained efforts of encouraging and training science teachers to develop their teaching practices to include argumentation, as it is a different approach to the everyday teaching practices of teachers. The constant consideration of alternative viewpoints and conflicting data, that teaching science as argument requires, is not a characteristic element of current science teaching (Duschl & Osborne, 2002; Lemke, 1990; Mercer et al., 2004). Consequently, 'teachers should be provided with training to act as facilitators of discussions on the implications of conflicting data and to be able to bring cognitive conflicts to light' (Limón, 2001, p.376). It is important to teach explicitly how argumentation can be effectively practised in a science classroom in order to move away from authoritative discourse and the dominance of the Initiation-Response-Evaluation form (Lemke, 1990) to one which is more dialogic and exploratory.

Thus, seeing argumentation as a dialogic practice is likely to challenge many, if not most teachers' beliefs about effective pedagogy and, for change to occur, teachers will need to be willing to adopt a more dialogic and student-centered approach of teaching (Simon, Erduran & Simon, 2006; Zohar, 2008). A dialogic approach seeks to place students at the centre of the teaching and learning process and establish a community of learners that can take control of their own learning and advance their understanding of the content, processes and values of science. Students need to become accustomed to activities where they have to share ideas and challenge one other so as to help each other learn. This community of learners should be characterised by the social norms demanded by the need for collaboration, the social context, the negotiation of meaning, and distributed expertise which teachers need to explicitly address in their argumentation lessons (Clark, Weinberger, Jucks, Spitilnik, & Wallace, 2003).

A view of argumentation as an epistemic practice places further demands on science teachers if they are to use argumentation as a framework for teaching. In particular, the use of argumentation by teachers and students is likely to be influenced by their epistemological understanding and conversely, the use of argumentation might influence the development of informed views of the epistemology of science (McDonald, 2010). Teachers using argumentation to teach science should have a deep understanding of the role and nature of scientific evidence and explanation and of the reasoning processes that scientists, and students, may go through in order to construct an argument. Such knowledge would constitute the ‘syntactic knowledge’ of teachers, one of four dimensions of teacher’s knowledge that influences their practice (Grossman, Wilson and Shulman, 1989). A firm grasp of the syntactic knowledge of science would enable teachers to include in their teaching questions such as ‘why’ and ‘how do you know’, which ask students to justify their beliefs, develop counter-arguments and make explicit the criteria they use for the selection of evidence to justify claims.

A view of argumentation as both a dialogic and an epistemic activity would enable science teachers to use the epistemic practices of science as a context for teaching the content of science (Grossman & Stodolsky, 1995). The perspective of ‘content as context’ in science education would enable science educators to teach not only the content matter of science but also the different methods and procedures scientists utilise as well as the epistemic criteria on which the justification and evaluation of knowledge claims are grounded. Nonetheless, studies show that teachers’ understanding of the NOS does not necessarily affect their teaching practices (Brickhouse, 1990; Lederman 1999). As

Lederman (1999) reports, even though the five biology teachers participating in his study, seemed to hold an informed understanding of different aspects of the NOS, they did not always consider the presentation of such issues to their students as important or worthy of mention. On the contrary, the amount to which the teachers addressed different issues of the NOS depended on factors such as their previous experiences as teachers, their objectives for their lessons and their views on students' learning. Similarly, even though teachers may understand the function of argumentation within the scientific community, they may not be able to transform that understanding into successful use of argumentation in the classroom. Science teachers, therefore, need to be trained into ways of using argumentation as an instructional approach, and these training opportunities, as will be discussed next, should be present both during pre-service training courses, and in-service professional development initiatives.

Zembal-Saul, Munford, Crawford, Friedrichsen, and Land (2002) investigated pre-service science teachers' ability to construct arguments on natural selection in a computer-supported collaborative environment. An in-depth exploration of the interactions of two pairs of pre-service teachers during the investigation revealed that these teachers had the basic skills of constructing arguments and supporting them through evidence. However, their use of evidence was problematic since it was limited to a few isolated elements of information that were used to support a claim, but which were never combined to strengthen the validity of their arguments. What is more, the participants did not state justifications or warrants that would explicate the causal link between the claim put forward and the information used as evidence. Finally, the two pairs of trainees did not consider or incorporate any alternative points of view in the construction of their arguments, and in this way, failed to engage in any evaluative practices. The authors also commented on the strategies the two pairs followed to create their arguments, which differed. The first pair chose to search for confirming evidence to the hypothesis they formed and ignored any anomalous data they came across during their investigations. The other pair took into account anomalous data they identified and changed their hypotheses accordingly. These results led the authors to conclude that 'conversations that explicitly attend to ways to explore data, the nature and quality of evidence, and alternative explanations for phenomena must become part of the social discourse of classrooms' (Zembal-Saul et al., 2002, p.455), explicitly stressing the importance of argument and discourse in both pre-service training and in-service professional development.

More recently, Zembal-Saul (2009) reviewed contemporary educational reforms on the K-8 level in the United States, which require students to engage in the social practices and discourses of science, develop their ability to coordinate theory and evidence, and be competent in scientific reasoning. She compared the policy document requirements with current practices and concluded that the new guidelines do not align with current practices in primary schools. Consequently, she argued that pre-service teachers need to learn how to teach science through a framework based on argument. A study conducted by Avraamidou and Zembal-Saul (2005) provides evidence that supports the view that including argument-based instruction in pre-service teacher training courses could improve the teachers' ability to use the principles of argumentation in their teaching practices. Specifically, Avraamidou and Zembal-Saul (2005) report on an in-depth case study of a novice teacher, who was successful in prioritising the use of evidence in her Grade 5 science lessons by providing several opportunities for students to collect, record, interpret evidence, and use them to construct evidence-based explanations. As this teacher commented, her teacher-training course (which was also the context of the study reported by Zembal-Saul et al., 2002) influenced her teaching practices in that it provided her with the experiences necessary for teaching science focusing on argument and the use of evidence in scientific investigations. Even though this study and Zembal-Saul's recommendations are based on primary education, the implications are easily transferable on the secondary education level, since if students are not introduced to ways of talking and thinking about science that are commensurate with argumentative practices during their primary education years, then they will not have developed the skills and social norms that would allow them to engage in argumentation activities during their secondary education years.

A study that focused on pre-service *secondary* science teachers is reported by Sadler (2006) who investigated the views of argumentation of a class of trainees as they engaged in an intensive 6-week secondary science methods course. The 17 participants of this study, engaged in activities that stressed the importance of constructivist and inquiry-based learning, critical thinking, and argumentation. As part of this 6-week course, participants had the opportunity to engage in explicit instruction of argumentation based on Toulmin's Argument Pattern (TAP), argument construction, evaluation of evidence and counter-argument. They also had to plan lessons or parts of lessons, which had a focus on discourse and argumentation, video-record them and reflect on them. Data from the students' work and reflections revealed that prior to the course, participants considered the importance of evidence for scientific practices, but only two mentioned argument and discourse as part of scientific endeavour, without being explicitly prompted to do so. What is more, discourse within science education was viewed as a pedagogical approach to promoting science learning rather as a characteristic of scientific practices that should be presented to students.

At the end of the course, most participants were able to consider the important role of argumentation within the scientific enterprise, but chose to ignore that importance when it came to science education. In particular, these trainees had discussed how argument-based strategies could be utilised to promote or consolidate conceptual understanding, but did not consider argumentation as an educational goal, able to frame science teaching and learning within a classroom. Such views are dangerous as they might lead prospective teachers viewing argumentation and group-work as synonymous and ignoring the epistemic nature of argumentation. Viewing argumentation as another way of doing groupwork would not emphasise the essential role of argument in the practice of science. Therefore, it could be argued that the teachers' views of the epistemic nature of argumentation need to develop in parallel to their understanding of argumentation as an instructional dialogic approach.

Another aspect investigated by Sadler (2006) was the participating pre-service teachers' argumentation skills. The participants had the opportunity to construct and evaluate arguments four times during the course, and the majority of them were able to produce arguments of higher quality at the end of the course and at the end of the semester, 10 weeks later. The improvement on argument quality was based on the participants' ability to include counter-claims and rebuttals to their argument structures. This ability to evaluate arguments was also considered at the two end-points of the study (end of course and end of semester) with all participants able to make evaluative judgements about the quality of two arguments presented to them. Compared to the results reported by Zembal-Saul et al. (2002), the participants of this study did considerably better, especially in argument evaluation, which was attributed by Sadler (2006) to the explicit instruction of the TAP argument structure, which required the consideration of counter-positions and rebuttals. Moreover, the participants in Sadler's study were well prepared to engage in argument construction from the outset of the study, with 15 of the 17 participants able to use the TAP structure to construct arguments at the start of the course. However, an issue of concern for Sadler (2006) was the ability of his participating students to distinguish between data and warrants. He mentioned that 25% of the times that participants attempted to apply the TAP model to evaluate arguments they failed to make the distinction between data and warrants, an issue Sadler attributed to the complexity of the TAP model. Overall, the pre-service teachers of this study were able to engage in argument construction and evaluation successfully, but their understanding of the use, and place, of argumentation in science education was restricted to that of argumentation as an instructional strategy for group-work that promoted discussion rather than as a reasoning process that was part of the scientific practice and which could constitute an overall, authentic approach to science teaching and learning. This lead Sadler (2006) to conclude that the expectation that pre-service teachers embrace a perspective of science education based on the principles of argumentation might be ‘unrealistic’, and thus efforts to make argumentation part of current science education should also be extended to in-service teacher education.

Further insights into the nature of the challenge argumentation poses for teachers come from the work of Martin and Hand (2009) who report a case study of a fifth grade science teacher that attempted to incorporate argumentation features into her everyday practice as part of a two-year, in-service professional development program. The results of this longitudinal study suggest that the role of teacher questioning for successful implementation of argumentation in science learning is vital. In particular, as the types of the teacher’s questioning moved from an IRE pattern with a low cognitive demand on the students to questions that had a greater cognitive demand, the student’s voice in the classroom was increased. What is more, as the student’s voice in the classroom increased and students were given greater control over their learning, they also started participating in argumentation activities more systematically. Consequently, students were able to create, evaluate claims and support them with evidence as well as rebut other arguments.

What is also important to note, is that the pedagogical practices of the teacher in their study, which encouraged the creation of arguments by the students, only showed a notable change from a teacher-centered approach to a student-centered approach in the *last six months* of the professional development program. Such conclusions stress the level of difficulty and the time required for effective change of pedagogical practices; a change which proved necessary for the successful implementation of argumentation in the classroom in Martin and Hand's study. Therefore, any effort to implement argumentation should allow teachers time to experiment and gradually develop skills and competencies in teaching science as argument, dependent on their existing abilities and/or knowledge of argumentation.

Another contribution to the field of professional development to promote argumentation in science education is the 'Enhancing the Quality of Argument in School Science' project (Osborne, Erduran & Simon, 2004a, 2004b; Erduran, Simon & Osborne, 2004; Simon, Erduran & Osborne, 2006). This group of researchers recognised that 'introducing argumentation requires a shift in the normative nature of classroom discourse' (Osborne et al., 2004a, p.997) and had therefore, worked with 12 teachers developing instructional sequences and materials that could promote collaborative discourse and argumentation in science classrooms. The materials were based on nine different frameworks, which could promote argumentation in the classroom (Osborne et al., 2004b). For the duration of one year, the teachers met six times and worked with the researchers in developing the argumentation materials and reporting on their attempts to teach argumentation. Simon et al. (2006) assessed the 12 teachers' quality of argumentation at the beginning and end of the first year, where statistically significant changes were identified for five teachers, who provided higher quality argumentation at the end of the first year in terms of the combinations of claims, data, warrants and backings identified in their arguments.

Simon et al. (2006) also explored the instructional practices of five teachers (with and without significant changes in the quality of their argumentation lessons as reported above). The qualitative analysis of their lesson transcripts revealed an array of argumentation processes reflected in the teachers' talk. These processes were: talking and listening; knowing meaning of argument; positioning; justifying with evidence; constructing arguments; evaluating arguments; counter-arguing/debating; and, reflecting on argument process. The teachers' use of these argumentation processes was enhanced from the beginning to the end of the year, although change was not noted for all processes and all teachers. Further, it seemed that the use of the various instructional practices identified was dependent on the teachers' initial understanding of argumentation. Moreover, as with the results reported by Zembal-Saul et al. (2002) and Sadler (2006) for pre-service teachers, the five teachers' engagement with evaluative practices such as counter-arguments, was not as prevalent as the teachers' construction of arguments through the use of evidence. These results further support the outcomes of the Martin and Hand (2009) study, which point out that teachers need to engage in argumentation for long periods in order to adapt their practices to include the different components and principles of argumentation.

In addition to allowing sufficient time for experimentation and development of pedagogical strategies in line with argumentation, there are other considerations to be taken into account. For instance, Duschl and Osborne (2002) maintain that there are two main requirements for successful implementation of argumentation in the science classroom. Firstly, students must be provided with the resources that will help them construct their arguments; the information and data that can be used as evidence for or against a claim. Secondly, science lessons should be constructed in such ways that would offer students opportunities for engagement in interactive discursive activities. Such dialogic engagement could take place both in groups and/or in whole class settings so as to help students talk to each other, listen to other arguments and construct their own.

Adding to Duschl and Osborne's (2002) two main conditions for implementing argumentation, are a number of considerations that science teachers need to take into account as they engage in argumentation activities with their students identified in a study conducted by Mork (2005). The 23 student participants, aged 14-15, of this study spent four lessons examining a controversial issue using computer software, which provided them with information about different viewpoints on the issue investigated. Subsequently, students spent two lessons conducting a number of role-play debates in groups of 3-4 students during which the teacher acted as a moderator. The analysis of the teacher-student discourse that took place during the debates illustrated the presence of several issues that required the teacher's attention. The issues identified include challenging the correctness of the information and claims students were providing; extending the range of the topic students were covering as they created and/or presented their arguments; getting debate back on track when necessary; keeping the debate or student discussions alive through elaborating on students' answers, changing the focus of the discussion and challenging students to provide more reasons and evidence for their claims; encouraging the involvement of more students in the discussions; and finally, a focus on debate techniques the students used as to help them develop their argumentation skills. In Mork's study, the two main requirements suggested by Duschl and Osborne (2002) were present as the students were provided the necessary information for argument construction through a software and opportunities of dialogic engagement were created in the form of role-play and debates. Yet, the teacher needed to take into account the additional factors mentioned above to ensure the quality of students' arguments and their active engagement in the debates. This body of work would suggest that implementing argumentation can be very challenging even for experienced teachers since it often requires teachers to step out of their teaching comfort zone and apply unfamiliar teaching strategies, such as debates and group work.

Teaching science as argument is not only a challenge for teachers but for students as well, who have to develop particular argumentation skills if they are to successfully engage in this form of talking and reasoning and benefit from it. Osborne et al. (2004a) maintain that 'argument is a form of discourse that needs to be appropriated by children and *explicitly taught* through suitable instruction' (p.996-7, emphasis in original). Two issues are of concern here. Firstly, teachers will have to be trained on how to use argumentation as an instructional approach, as discussed above. Secondly, students would need to be introduced and accustomed to this way of learning science, which is again a condition dependent on the teacher's ability and willingness to use dialogic argumentation as an instructional approach.

Students' unfamiliarity with group work is a challenge that teachers would need to overcome as they start using argumentation activities in their lessons. Blatchford, Kutnick, Baines & Galton (2003) based on their examination of the state of group work in British schools mention that only 1 in 3 students have received some type of training in group work at the secondary school level. Thus, group-work is an aspect that students need to be educated in and about since students need to develop interpersonal and small-group skills (Gillies, 2003; Johnson & Johnson, 1994; Kutnick & Rogers, 1994), and an awareness of conversational ground rules (Mercer, 2000), to engage successfully in group-work activities. As Johnson and Johnson (1994) maintain, social skills such as decision-making, communication and conflict management skills, which are also essential elements of argumentation engagement, can, and should, be taught to students before engaging them in different types of collaborative group activities. Moreover, group formation should be planned with specific educational aims in mind, if group work is to be successful (Blatchford et al., 2003). These issues need to be considered when teachers are planning lessons, which include collaborative argumentation activities. Having students seated in groups does not necessarily mean that students will engage in productive group work (Blatchford & Kutnick, 2003). If students are not trained to act as members of a group and see the benefits from working within a group, then the level of difficulty of incorporating argumentation activities in science lessons will be even greater than when students are provided with the training and support necessary of engaging in group-based activities. Finally, students need to perceive the need and potential benefits of engaging in argumentation activities for them, in order to participate in a meaningful way in such learning (Kuhn, Wang & Li, 2011).

In addition to training and exposing students to dialogic teaching and group work, argumentation instruction needs to be designed in such a way that students will be provided with the evidence and linguistic repertoire that will help them construct and support their arguments. For instance, Voss and Means (1991) argue that to be in a position to reason successfully, students should (a) have knowledge of the structure of arguments and be able to use meta-language related to argumentation, such as ‘claims’ and evidence’; (b) be made aware of the need to evaluate arguments based on a set of criteria; (c) be aware of the purpose of an argument-based activity within a specific context; (d) be able to distinguish what makes a good or bad argument; (e) be able to not only argue in oral situations but also provide written arguments. These five conditions for engaging in successful construction and evaluation of knowledge claims need to be modelled by the science teacher through classroom talk and through the activities students are asked to engage in during science learning.

Webb, Nemer and Ing (2006) have studied the role of teacher talk and the influence of this discourse on students’ discourse and interaction over a semester. They concluded that the teacher rarely asked students to explain their answers or thinking and did not encourage question posing by the students. Interestingly, when the discourse between students working in small groups was examined, the same questioning and reasoning patterns and interactions were evident, which led the authors to conclude that student discourse models the teacher discourse and the expressed expectations of the teacher. Similar results are presented by Gillies and Khan (2009), who trained teachers working in different groups, to pose questions that challenged their students’ thinking and reasoning skills, and then examined the influence of the teachers' questioning techniques on their students' ability to collaborate when in groups. Teachers in the cooperative-questioning group were trained on ways of teaching students how to formulate questions that stimulate thinking and promote reasoning and problem-solving skills. Teachers in the cooperative-only group were trained into ways of embedding cooperative activities in the curricula. Gillies and Khan (2009) found that the students, whose teachers belonged to the cooperation-questioning group, were better able to pose questions and provide justifications and reasons in their interactions within groups, as opposed to students whose teachers were not trained to use questioning in addition to collaborative teaching techniques. Gillies and Khan (2009) conclude that:

> 'when students are placed in situations where they are expected to work cooperatively and they are taught, both explicitly and implicitly, how to ask questions that challenge each other's thinking during their discussions, it makes them aware of the importance of providing detailed responses that are elaborated and helpful to their cooperating peers' (p.22).

Although the studies reported by Webb et al. (2006) and Gillies and Khan (2009) focused on mathematics education rather than science education, they are important for they provide evidence to support the view that the teacher and the types of talk that is promoted by him/her, is fundamental for the ways in which students will develop, or not, their own thinking, questioning, and argumentation abilities. The teacher functions as 'an enabler of talk for thinking' (Myhill, 2006, p.21) and not as the controller of students' talk. Thus, it is assumed that modelling the discourse of science based on argumentation, with an emphasis on epistemic aspects of science, would enhance students' ability to explicitly and purposefully use evidence to support their ideas or rebut other students' arguments and would help them develop the ability to ask critical questions and be reflective of the processes they engage in. Consequently, teachers need to adopt a particular way of talking in order to model the types of talk that wish their students to adopt and utilise in order to learn science through argument. Argumentation should be utilised by teachers as a way of introducing students to the ways that the scientific community functions and scientific knowledge is produced and validated to promote an informed view of science as a way of knowing (Driver, Asoko, Leach, Mortimer & Scott, 1994).

The reviews of studies in this section show that although both pre-service and in-service science teachers have the basic ability to engage in constructing arguments, they are less able to engage in the evaluation of arguments. Moreover, current practices and training courses are not aligned with reform and policy documents that require the use of argument and discourse as part of science learning and teaching. Training courses such as those reported by Sadler (2006) and Zembal-Saul et al. (2002) are not the norm in current teacher education programmes. In fact, little research exists on approaches to promote the use of argument in the classroom, both through pre-service programmes and through in-service professional development initiatives (Zohar, 2008). As a consequence, both existing and training teachers are not likely to be familiar with argumentation, both of its epistemic or dialogic nature, and collaborative discourse activities would not often be observed in science classrooms. What little research there is would suggest that appropriating argumentation as a regular instructional practice takes time (Martin & Hand, 2008; Simon et al., 2006). Therefore, there is a need for science education researchers and science teachers to work together to promote the implementation of argumentation in the science classroom over a sustained period of time.

In light of such considerations researchers at King's College London and the Institute of Education have collaborated to develop an in-service professional development programme, which aimed to assist teachers transform their practice towards a dialogic pedagogical approach with a particular focus on argumentation. This research project, called *Talking to Learn, Learning to Talk in Secondary Science* constituted the context within which the current thesis was built, and it is therefore, described below.

2.4 The 'Talking to Learn, Learning to Talk in Secondary Science' Project

The *Talking to Learn, Learning to Talk in Secondary Science* (T2L hereafter) project is a collaborative effort by researchers at King's College, London and the Institute of Education funded by the Economic and Social Research Council. The main objective of the T2L project is to promote the utilisation of argumentation in science at the secondary school level. The approach of teaching science through argumentation can be seen as a move away from a pedagogy of transmission and a representation of science as a '*rhetoric of conclusions* in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths' (Schwab, 1962, p. 24, italics in original). The aim of using argumentation for science learning is leaning towards a dialogic pedagogical approach such as the one advocated by Alexander (2005), as collective, reciprocal, supportive, cumulative and purposeful. Professional development programmes have been supported as a way towards promoting learning and changing pedagogies (Borko, 2004) and therefore are considered as an appropriate route to developing the use of argumentation in the science classroom. The first research question of the T2L study was:

1. *Does a cycle of reflective professional development based on the use of argumentation transform science teachers' pedagogic practice to one that is more dialogic?*

To provide answers to the first research question, a two-year professional development programme has taken place focusing on helping science teachers from four intervention schools within inner and suburban London, as well as their science departments, incorporate argumentation into their everyday practices. Within each intervention school, two teachers acted as lead teachers for their departments. The lead teachers attended five workshop days at King's College London, where they were introduced into the practice of argumentation, helped develop their knowledge of implementing argumentation in their science classrooms, and worked towards a dialogic perspective of science instruction. Subsequently, these eight teachers acted as lead teachers for their departments organising departmental reflective meetings and providing support to the science teachers of their own departments, which attempted to use argumentation activities in their science lessons.

The second major focus of the T2L project was student learning. One of the main assumptions leading this project was that dialogic engagement promotes effective learning as well as a positive attitude towards science. Particularly, the influence that argumentation had on students' cognitive abilities, attitudes towards science and personal and formal epistemologies were investigated.

The research questions focusing on students were:

2. *Does engaging in argumentation lead to any observed improvement of students' conceptual learning?*
3. *What effect does engaging in argumentation have on students' understanding of the Nature of Science?*
4. *What effect does a more discursive/dialogic pedagogy have on students' engagement with science?*

For this purpose, two classes of Year 7 students and two classes of Year 9 students from each of the four intervention schools (n=480) were pre- and post-tested on their cognitive abilities, attitudes towards science and epistemological beliefs and understanding. Students from four other schools in inner and suburban London (n=480) were given the same assessment tools acting as a control group to allow comparisons between the two groups.

This thesis has been developed within the T2L project. The stance taken is that argumentation is both an epistemic and dialogic activity. As the T2L project placed emphasis on the dialogic aspect of argumentation, the present thesis focuses on the epistemic aspect of argumentation. As discussed, the role of the teacher is instrumental for the way that argumentation will be presented and understood by students. Therefore, particular interest is placed upon the ways in which science teachers participating in the T2L project implement argumentation. The investigation of argumentation is framed on a conceptualisation of science as an epistemic practice, and its presentation in the science classroom through language. The argument put forward is that argumentation as a teaching approach can facilitate the development of epistemic discourse in the science classroom and the presentation of science as an epistemic practice. In the next chapter, these issues are explored in more detail.

CHAPTER 3

SCIENCE, EPISTEMIC PRACTICES AND ARGUMENTATION AS EPISTEMIC DISCOURSE

So far in this thesis, it has been argued that argumentation is an important reasoning practice of the scientific enterprise, which has several advantages for science education. One of the ways argumentation can influence positively students' understanding of the NOS is through the presentation of science as an epistemic practice. Epistemic practices are those activities that aim to create justified knowledge, and in this chapter, argumentation is presented as a process characteristic of epistemic practices. This chapter begins with an introduction and description of the epistemic practices of science, which, as argued by Longino (1990, 2002), are both rational and social. As will be discussed, scientists have different ways of reasoning, as individuals and collectively. The dual nature of the scientific knowledge and enterprise – as both social and rational – is also characteristic of argumentation (Duschl & Osborne, 2002). Scientists, while engaging in argumentation, utilise a special kind of discourse that in this thesis is labelled 'epistemic discourse'. This way of talking is necessary for the creation, justification and evaluation of knowledge claims, all of which are actions central to the epistemic practices of science (Kelly, 2008, 2011). Therefore, epistemic discourse and its value for learning science is discussed followed by a review of research attempts to describe, analyse or promote epistemic discourse in the science classroom at the K-12 level.

3.1 SCIENCE AS AN EPISTEMIC PRACTICE

One of the central aims of the scientific enterprise is to explain the natural world. In order to do so, scientists propose, investigate and develop scientific theories, which model nature (Harré, 1984). During knowledge construction and legitimisation of knowledge claims, scientists engage in a series of decision-making processes and selections of ways of acting and reasoning (Knorr-Cetina, 1981). The selection of one set of data over another to count as evidence for a knowledge claim, the preference to a particular methodological approach and research design, or the ways in which empirical results will be presented to the scientists' disciplinary community to convince them for their significance, are only a few of the choices scientists need to make during their investigations. The various processes and activities in which scientists engage in are *epistemic* since they aim at the generation of knowledge that is justifiable and accountable to the scientific community's norms and expectations. Epistemic practices are defined by Kelly (2008) as 'the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework' (p.99). Characterising the practices of science as 'epistemic' signifies the central objective of science, which is to ascertain what is known of the natural world, and in this process, create and establish knowledge through justificatory, and social processes.

3.1.1 Social and Rational Practices of Science

Longino (2002) argues that a comprehensive account of the practices of science needs to include both the social and rational characteristics of scientific practices. On the one hand, scientists engage in rational activities, defined by Longino as those focusing on justification based on evidence and logical reasoning. On the other hand, scientists engage in activities that are social in nature, such as those emphasising social interaction and non-evidential considerations. Yet, the social and rational dimensions of scientific endeavour are not in opposition. Hence, scientists' thinking and acting is both formed based on rational criteria and bounded by social interaction. As a consequence, '[scientific] knowledge is produced by an amalgam of heterogeneous acts and not by a particular kind of truth-producing activity guided by logic' (Longino, 2002, p.7).

The social context of the community in which scientists function is important, as it can influence their reasoning and thinking processes (Dunbar, 1995, 2000). Dunbar (1995), through studying scientists in eight different laboratory settings, found that scientists working and discussing experimental results as groups, tended to hold onto any inconsistent evidence produced and focus on extending or creating alternative hypotheses to explain disconfirming evidence. Conversely, scientists working individually had the tendency to consider evidence inconsistent with their hypotheses as errors and to disregard them, instead of further examining the anomalous data. Such results support the view that scientists' selection of how to act and of their reasoning trajectories are based on values, beliefs and assumptions not adopted by individual scientists, but rather by groups of scientists (Kelly, 2008, 2011; Knorr-Cetina, 1981; Longino, 1990). This would suggest that social and rational practices are inter-related, since background beliefs and assumptions are utilised to demonstrate how a particular set of data may constitute evidence for or against a hypothesis, and can therefore facilitate or constrain scientists' attempts to move from data to evidence, to a scientific theory, and vice-versa. Namely, scientific theories and the way that are dealt with or accepted by scientists, influence the types of research that is undertaken or funded in a way that is bounded by social interests and interaction.

3.1.2 Evaluative practices of science

The evaluation of knowledge claims – one of the epistemic practices of science (Kelly, 2008) – is influenced by scientists' commitment to particular epistemological paradigms. This commitment can result in adopting distinct epistemic criteria for knowledge development and evaluation (Longino, 1990). For example, moving away from the view of science as an individual and isolated practice to one that encompasses the social and interactive nature of scientific practice is a fundamental change in epistemological perspectives, which explicitly emphasises the social character of the scientific enterprise.

Within science, a move towards a social conceptualisation of science would put more weight on the social norms shared by the scientific community (Kuhn, 1962) as well as on the discursive practices of scientists. However, it is worth mentioning that the emphasis placed on the social character of science does not result in scientific practices being relativistic, as critics of this approach would suggest (Chalmers, 1999). It is still possible to maintain a level of objectivity since common criteria and rules would apply, against which evaluative processes could take place. In fact, Longino (1990) discusses how considering science as a social activity does not require a rejection of objectivity in the sciences. On the contrary, she maintains that objectivity is 'a matter of degree' (p.76) and considers how critical discourse is an essential part of scientific practices. As Longino (1990) argues:

> 'A method of inquiry is objective to the degree that it permits *transformative* criticism. Its objectivity consists not just in the inclusion of intersubjective criticism but in the degree to which both its procedures and its results are responsive to the kinds of criticisms described' (p.76, emphasis in original).

She provides four criteria through which a particular scientific community can maintain objectivity. The first criterion against which a scientific knowledge can be judged for its ability to produce objective knowledge is the existence of recognised avenues for criticism such as peer review, public forums and conferences. The second way of achieving the critical discourse required for objectivity is the creation of shared standards among the members of a scientific community. Thirdly, the scientific community must be characterised by responsiveness to the criticisms that are taking place. Finally, intellectual authority should be equally directed amongst the members of the community for new assumptions and beliefs to be equally treaded within the community and not rejected on the basis of political or intellectual authority. Scientists' shared understanding and use of these criteria as 'regulators of critical discourse' (Longino, 2002), is what distinguishes one community from another. Within each scientific community criteria for evaluating knowledge might vary which requires scientists communicating their results in ways that can be shared both within their own research groups, and, to groups or communities outside their disciplines.

3.1.3 Communicative practices of science

The communication and representation of knowledge to a wide range of audiences is another issue to take into consideration in exploring the epistemic practices of science (Kelly, 2008). The ways in which a proposed and justified knowledge claim is presented to a particular disciplinary community to convince other scientists of its importance, validity and reliability, is vital for the acceptance of this knowledge claim. Having the appropriate empirical evidence and structured reasoned arguments for a claim, does not necessarily mean it will be immediately and consensually accepted. According to the degree that this knowledge claim is justified, and, to the degree that the scientific community accepts it, a claim can be transformed into a taken-for-granted fact.

Latour and Woolgar (1979) discuss how statements that have taken the status of 'facts' may not even need to be explicitly mentioned in scientific conversations. These authors provide an account of the transformative phases that an assertion expressed within the boundaries of a laboratory goes through, until it can be considered as a taken-for-granted factual statement, as presented in Table 3.1.

Table 3.1: Types of statements and their progressive facticity as presented by Latour and Woolgar (1979)

	Nature of statement	Example	Usually appear in…
Type 1	Statements as conjectures or speculations	*It may be that A…*	End of papers or private conversations among scientists of a group
Type 2	Statements as claims or tentative suggestions	*There is evidence to suggest that A…*	Papers and drafts circulated within a group of scientists
Type 3	Statements referring to other statements	*It has been reported by Smith (xxxx) that A relates to B*	Review and published papers usually including a reference
Type 4	Statements without any qualifying modalities	*'A relates to B'*	Textbooks and teaching materials
Type 5	Taken-for-granted statements	–	Conversations and/or papers addressed to members of the community
		'A'	Conversations with individuals outside the scientists' discipline

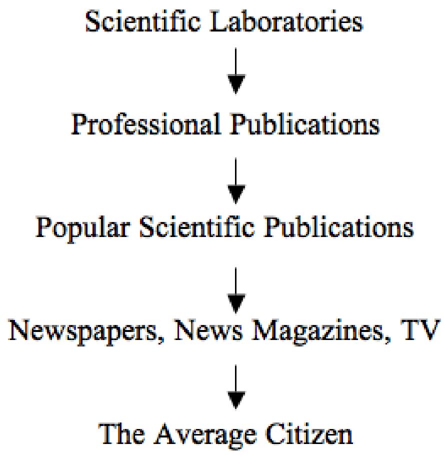
A Type 1 statement is of a conjectural nature and is the initial form of what could later be considered as a fact. A fact, or a Type 5 statement, is often so obvious to the members of a discipline or a group of scientists that may not even be explicitly stated. A Type 5 statement needs to be explicitly expressed only when individuals outside the scientists' discipline require further information. Presenting and understanding science as an epistemic practice requires individuals to know and understand the processes, through which this knowledge has come to be, as well as its limitations and the background assumptions on which this knowledge was based and built.

Consequently, individuals need not only to learn the end-product of this epistemic practice, that is the Type 4 and 5 statements. Individuals also need to be aware of the existence of Types 1, 2 and 3 statements and of the routes that assumptions, beliefs and ideas go through before they are finally accepted as scientific knowledge. As Longino (1990) states, it is important for citizens to be in a position to ask epistemic questions like 'What is the evidence? Why is this data evidence for this hypothesis? Why should I believe this?'(p.61), if they are to make sense and be in a position to use this scientific knowledge. In the same way, it can be argued that citizens need to be aware that they need to address these epistemic questions that Longino mentions. But, where and how do individuals acquire such awareness and ability to enquire the epistemic status of scientific knowledge? These critical dispositions need to be explicitly addressed through science education and in particular, in the science classroom.

Science instruction should introduce students to practices that incorporate the creation and consideration of Type 1 and 2 statements, in addition to providing students with the facts of science. The inclusion in science education of tentative statements which require qualification based on evidence, as the Type 1 and 2 statements would require students to engage in epistemic practices such as the social and rational practices of science, and the evaluative processes that knowledge claims go through, as these were presented in Sections 3.1.1 and 3.1.2. The importance of presenting science based on a framework of epistemic practices is based on the opportunities that these offer to science educators to present students with the transformative phases knowledge claims go through as they are both communicated and justified to produce reliable knowledge.

It is essential to realise that knowledge goes through a number of alterations and transformations from the instance that a piece of experimental evidence is created in a scientific laboratory to the moment that it will reach individuals outside the scientific community (Giere, 1991). Coming to understand this process means that individuals will have a better understanding of the nature of scientific knowledge and of the ways in which it is produced and then presented to the public. In this way, they can be critical of that knowledge. Giere (1991) describes this process of transformation through written reports (Figure 3.2). This transformation of scientific knowledge, which serves different purposes depending on the audience that is addressing, is knowledge that students learning science need to acquire to be able to engage in the 'critical discourse' that Longino (2002) mentions as to become active citizens of their societies.

Figure 3.2: Transformation of scientific knowledge through means of publication (Giere, 1991, p.6)



The epistemic practices of science aim at the development of empirically and theoretically sound scientific knowledge about the natural world. The knowledge formed is constructed on experiential evidence and it concurs with the epistemic criteria set by the community of scientists within which this knowledge was produced. Duschl and Grandy (2008) state that 'the practice of science consists of a complex interaction between theory, data and evidence' (p.33) and that the primary means through which these interactions are made is dialogue and argument. Therefore, the dialogic and argumentative processes through which knowledge claims put forward by scientists, and by which they advance, are an indispensable part of the epistemic practices of science.

The argumentative interactions of scientists within a community are primarily discursive in nature (de Vries, Lund & Baker, 2002), through written and oral communication acts. Similarly, observation and reasoning – core processes of the scientific practice – become dialogical activities, 'involving discursive interaction among different voices' (Longino, 2002, p.99). Therefore, the discourse produced through engagement in argumentation is *epistemic* and could be seen as a way of using language 'to explore the *testable*, *revisable*, *conjectural*, *explanatory* and *generative* nature of scientific ideas' (Windschitl, Thompson & Braaten, 2008, p.311, emphasis in original). In this respect, epistemic practices can be viewed and described through discursive actions, which are expressed through talk, representational tools such as diagrams and models, or through written text. No matter what the form they appear in, these actions are epistemic as they aim to create new knowledge in a systematic and justifiable way.

3.2 Using Epistemic Discourse to Talk Science

A way to foreground the epistemic aspects of science within science education and structure classroom talk is to enhance the use of collaborative discourse and argumentation in the teaching of science (Driver, Newton & Osborne, 2000; Erduran & Jiménez-Aleixandre, 2008). As discussed in Section 3.1, argumentation is a discursive and reasoning process characteristic of epistemic practices. Through the teaching of science as argument, students and teachers engage in epistemic discourse. Epistemic discourse is the dialogic engagement in which students and teachers participate in an attempt to produce knowledge claims with evidentiary support (Sandoval & Morrison, 2003). Moreover, epistemic discourse includes the process of evaluation of knowledge claims in order to provide further support for their validity. Thus, epistemic discourse could include instances of asking for evidence to support and justify a claim; making students consider opposing views and critically evaluate which one is better and why; explicit mention of the nature of evidence that students need to be using in their explanations and of the role of this evidence for their arguments; and providing or creating counter-arguments. That is, epistemic discourse could be developed through the teaching of science as argument.

The use of epistemic discourse to teach and learn science is considered as an alternative to the traditional patterns of classroom discourse that dominate science classrooms, such as the Initiation-Response-Evaluation (IRE) pattern (Lemke, 1990) and the presentation of factual knowledge to the students (Schwab, 1962). The seminal work of Lemke (1990), who studied the talk that takes place in science classrooms, signifies the important role that language has on students' learning of science. Lemke (1990) advanced the idea that when students learn science, they not only learn the language of science but also ways of reasoning using this specialised way of talking, and thus, 'learning science is learning to *talk* science' (p.1).

Lemke's analysis of how language is used to teach science in secondary education reveals the development of a 'mystique of science' (Lemke, 1990, p.129). This conception seems to be the result of the formal and specialised language used in science classrooms that often develops the idea that only *one* right way of talking and practising science exists. As a result, a view of science as authoritarian and 'special' is promoted, which projects to students science as being in a constant opposition to the everyday world. The classroom talk that Lemke (1990) described was likely to be dominated by detailed descriptions and definitions of scientific phenomena with fewer opportunities for modeling, use of evidence and contrary theories and viewpoints, and thus fewer opportunities for the development of epistemic discourse.

Another set of factors that contribute towards the development of the mystique of science is what Lemke (1990) identifies as the 'ideology of the objective truth' and the 'ideology of the special truth of science'. The former refers to the belief that scientific knowledge consists of facts that are objective and true, and that students need to memorise, usually without any discussion of their theoretical background. The latter considers scientific knowledge as a 'special' kind of knowledge that only a few are able to understand and use. Such 'science teaching conveniently ignores the wrecks and ruins of major theories, and "facts", of past generations' (Lemke, 1990, p.143) reinforcing misconceptions about the nature of scientific knowledge and practice and leading students' interests away from science, which is perceived as a difficult school subject. Lemke's considerations provide support to the view that the representation of scientific knowledge and practice through classroom talk promotes certain ideas about science, which are not in agreement with contemporary perspectives on the NOS. As a result, ways of structuring classroom talk in order to present a more accurate picture of scientific practices are needed. To present a better understanding of science, science instruction needs to include not only the content of science but also the epistemic values and assumptions, on which this content is based. That is, science should be presented to students as an epistemic practice.

Sandoval and Morrison (2003) suggest that epistemic discourse in science education is able to help students advance their understanding of the epistemology of science. These authors state that participation in activities where students need to construct their own explanations and provide evidence to support these explanations *without emphasis on the discourse* that takes place during these activities does not necessarily help students develop an informed epistemological understanding. In their research, the students on which they focused had the opportunity to engage in such inquiry activities but at the end of the study, they did not demonstrate any substantial improvement to their understanding of the nature and role of scientific theories and evidence. The authors add that students, in addition to engaging in such activities, need to be provided with opportunities to discuss the reasons and criteria they use for choosing one explanation over another, as well as to discuss the role of evidence for their explanations. As a consequence, Sandoval and Morrison (2003) suggest that 'to develop students' epistemological ideas, *the nature of the discourse surrounding students' inquiry may be more important than the inquiry itself*' (p.383, emphasis added). If engaging in epistemic discourse is crucial for students' development of NOS understanding, then 'the nature of the discourse surrounding students' inquiry' needs to be identified. Yet, the question to be asked is: How can such epistemic discourse be identified and characterised in the science classroom? What is more, if argumentation can be used as a teaching approach to promote epistemic discourse, as argued above, then, specific epistemic features of argumentative discourse that enable students to develop their understanding of the nature and practice of science also need to be investigated and identified.

Windschitl et al. (2008) maintain that science teacher training needs to systematically address the relationship between evidence, theory and explanations in order to help student teachers incorporate these elements in their practices. The way the science teacher presents science in the classroom, is one of the key features of science learning and instruction (Mortimer & Scott, 2003). Thus, the language utilised to present science in the classroom is an important feature of the way that students come to understand, use and view science. Epistemic discourse has to be promoted and established by the teachers, who have to be aware of ways of promoting this particular way of talking in their classrooms. Therefore, research that carefully explores the epistemic discourse of science classrooms is needed to determine how it is used by different teachers in different classrooms, and the ways in which science teachers establish the epistemic grounds of scientific knowledge for their students through language.

As it will be discussed in the next section, there are only a few studies that focus explicitly on the analysis of epistemic discourse, and the role of the teacher in promoting this type of talking within science classrooms. This signifies the need for further investigation and analysis of classroom discourse from an epistemic perspective.

3.3 Epistemic Discourse in the Science Classroom: a Review of the Literature

An explicit attempt to make connections between the science teachers' discourse and their students' conceptions about science is offered by Zeidler and Lederman (1989). These researchers investigated whether the ways science teachers used language in the classroom affected their students' ontological understanding leading them towards a realist or instrumentalist perspective. To do this, they collected data by pre- and post-testing 18 biology teachers and their students over the period of a semester. The teachers were asked to complete the *Nature of Scientific Knowledge Scale* (NSKS) questionnaire, as did one class of students for each teacher, at the beginning and end of a semester. For the classification of teachers' talk they used a framework based on six variables (Testable; Developmental; Arbitrary constructs/Models; Anthropomorphic Language; Creative; Objective/Subjective) developed from previous research (Lederman & Drugher, 1985). Each of these six characteristics of scientific knowledge was defined based on Munby's (1976) distinction between the everyday language people use, which would lead to instrumentalist conceptions, and the language of science, which resulted into the development of realist views about science. The comparisons made showed that the students, whose teachers' discourse had an instrumentalist or realist orientation, demonstrated a change towards the same orientation as their teachers.

The conclusions drawn by Zeidler and Lederman (1989) demonstrate the influence that classroom discourse – as directed by the teachers – had on students' understanding of the ontology of scientific knowledge as directly describing reality or as a useful construction for explaining nature. This influence provides support to the view that the role of the teacher, and the epistemic discourse that s/he is utilising in the science classroom, are important for the development of students' use of epistemic discourse. However, ascribing the characteristic of instrumentalist or realist to the participant teachers' talk does not present the way in which these teachers engaged their students in any epistemic activities or discourse. Rather, it characterises teachers' discourse based on the ontological distinction between realism and instrumentalism. Within the science classroom, ontological and epistemological assumptions take form in the diverse discursive activities in which teachers and students engage. For example, if a teacher does not prompt justifications from students or does not allow students to consider alternative perspectives and arguments then it is likely that these students will come to see science as a stable, uncontroversial set of propositional knowledge. Hence, a more detailed analysis of the discursive activities of teacher and students is needed.

In a more recent attempt to explore the support that science teachers provide to their students through classroom discourse, Tzou (2006) focused on explanation. Tzou (2006) maintains that students have difficulty engaging in science and adopting the norms and ways of talking and acting of the scientific community. For instance, students are not familiar with the definition of scientific theories as well-structured and often complex explanations of scientific phenomena. Rather, students are more likely to use the term 'theory' as used in everyday contexts to refer to beliefs and tentative ideas. Therefore, one of the tasks that science teachers should be preoccupied with is their students' transition from the familiar, everyday understanding of the world to the scientific way of conceptualising the natural world. This particular study, focused on two teachers that taught the same eight-week unit of biology to eighth graders. The study was part of a larger project aiming at the development of curriculum materials that modelled the construction of scientific explanations through inquiry activities.

The two teachers were video-recorded during instruction of all the lessons of the biology unit they had to teach. Moreover, both teachers and students were interviewed at the beginning, middle and end of the study. Teachers were provided with four guidelines as suggestions of ways of supporting students in constructing scientific explanations. Specifically, teachers were prompted to make the explanation framework of 'claim, evidence, reasoning' – which is similar to Toulmin's argument structure – as explicit as possible and encourage their students to use all three parts of the explanation model in their own explanations. Furthermore, teachers were advised to model the construction of explanations during lessons, and create opportunities for their students to critique their own and each other's explanations.

The theoretical framework developed by Tzou (2006) to analyse the teacher's talk considered scientific discourse as consisting of cognitive (coordination of theory and evidence), social (communication of results and social interaction) and linguistic (definition and use of scientific terms) dimensions of inquiry. This multidimensional framework of inquiry mirrors the complex nature of scientific inquiry. The results of this study indicated that the three dimensions of inquiry identified interacted and influenced each other. For example, the support that one of the teachers provided by implicitly using the linguistic dimension through 'why' questions, could also help students develop their use of the cognitive dimension by indirectly prompting students to provide evidence to support their claims and create evidence-based explanations. In this way, students were both asked to provide justifications, engaging in this way in epistemic discourse, and were also requested to have the knowledge or understanding necessary to provide answers to 'why' questions. These linguistic and cognitive dimensions could also be able to help students realise the role of evidence in scientific inquiry and thus, enhance their epistemological understanding of scientific explanations, evidence and the coordination of the two. Moreover, the social and linguistic dimensions of inquiry were characterised by Tzou (2006) as embedded with epistemological assumptions, which are passed to the students through the discourse of science. However, this epistemic dimension, which could further identify instances of epistemic discourse in the classrooms that Tzou (2006) described, was not further explored within the frames of her study. Thus, the analysis of classroom talk provided through Tzou's (2006) study indicates some instances that could be identified as epistemic discourse by the teachers' prompts for 'why' and the students' provision of justifications through evidence, but the nature of such talk is not further elaborated or discussed.

One of the few studies that emphasise the epistemic dimension of classroom discourse is reported by Ryder and Leach (2008). They reviewed relevant literature on students' understanding of the NOS and classroom talk and identified four features of classroom talk essential for the successful development of students' epistemological understanding. The first characteristic of science teachers' classroom talk identified was the presence of any appropriate comments explicitly emphasising different aspects of the NOS to the students. The second feature of science teachers' discourse acknowledged as important was the presence of links made between NOS and science content. As the authors argue, aspects of the NOS should be embedded in the science topics taught instead of simply mentioning to the students general and out-of-context aspects of the NOS. For instance, statements like ‘scientific knowledge is tentative’ should not be generalised but should be presented through examples that show the meaning of this NOS aspect in particular contexts. Not all scientific knowledge is tentative to the same degree and this is where students may become confused about the distinction between the facts of science and more tentative ideas or ‘theories’. The third theme emerging from their literature review was the presence of any attempts to elicit students’ ideas of the NOS and how teachers work with these ideas to help students develop them. Finally, the fourth element of teachers’ talk to be looked for when teaching about the NOS was whether science teachers expressed the objectives of their lessons explicitly, at the beginning but also during the lesson. As the authors support, making the aims of the lesson known to students helps them understand why they are doing an activity and the activities become more purposeful.

Ryder and Leach (2008) applied the four characteristics of science teachers’ classroom talk identified to analyse seven science teachers’ talk as they taught about the development of theoretical models within the contexts of electromagnetism and cell membrane structure. Their analysis showed that even though teachers did not make any inappropriate comments about the NOS, often they were not in a position to elaborate on aspects of the NOS. Additionally, most of the teachers were not as confident in using students’ ideas about the NOS as a starting point for classroom discussions, an inability on the part of the teachers that could be attributed to their own conceptions of the aspects of the NOS discussed. If science teachers do not have an understanding of the epistemology of science that is comparable to the aspects they are asked to teach, then their confidence and ability to teach these NOS aspects is minimised (Brickhouse, 1990; Lederman, 1999).

The results from the Ryder and Leach (2008) study suggest that in an ordinary science classroom, it is unlikely that the science teacher will aim to elicit students’ understanding of aspects of the epistemology of science explicitly, unless this is the focus of the particular lesson, as was the case of the teachers in this study. As the literature supports, there is a need for explicitly teaching about the NOS if students are to develop their epistemological understanding (Khishfe & Abd-El-Khalick, 2002; Lederman, 2006). Yet, the teachers’ attempts to include aspects of the NOS in their lessons are often unsuccessful or limited by other factors as their beliefs and confidence, discussed above (Lederman, 1999). As discussed in Chapter 2, argumentation could be a way of placing emphasis on epistemic aspects of science without having to plan and organise lessons, which particularly address NOS aspects (McDonald, 2010).

A different analysis of classroom discourse, which specifically focused on argumentative and epistemic talk, is presented by Mason (1996). Mason (1996) conducted classroom observations of five fifth grade classrooms from two primary schools, focusing on the verbal interactions between teacher and student to evaluate the 'collective reasoning and arguing' that were taking place in the classroom during a unit on environmental education. A sociocultural perspective of learning was adopted for the development of this project, in which students worked collaboratively to construct a shared understanding of the ideas discussed in the classroom and in this process, they were helped or guided by their teachers.

The discourse produced by students was analysed based on argumentative and epistemic operations. This twofold framework was adapted from the work of Pontecorvo and Girardet (1993) that used a set of argumentative and epistemic operations to analyse fourth grade students' discussions of a history topic. The *argumentative* operations used by Mason (1996) were the same as those used in the Pontecorvo and Girardet (1993) study and consisted of *claim*; *justification*; *concession*; *opposition*; and, *counter-opposition*. The *epistemic* operations used by Mason were not the same as those suggested by Pontecorvo and Girardet (1993). Instead, Mason (1996) identified a new set of epistemic operations which, as stated by the author, could provide a closer representation of the scientific practices. The epistemic operations used by Mason were defining; identifying significant variables where students need to recognise that a particular variable is involved in a phenomenon; relating and establishing connections between factors and facts; generalising; applying metacognitive reflection on knowledge and knowing; and finally, appealing to different sources of knowledge like prior knowledge, experiences, given facts or, ways of thinking about the subject under discussion like analogies, thought experiments, counterevidence and coordination of theory and evidence. Mason (1996) concluded that a classroom environment that encourages classroom discussion, such as argumentation, could provide the context for the development of higher-order thinking and reasoning skills. This work provides support to the claims made by Sandoval and Morrison (2003) about the positive influence that epistemic discourse may have on students' epistemological understanding. Therefore, if epistemic discourse is to be established in science classrooms to assist students' development of the NOS, epistemic features as the ones presented in Mason's study based on 'epistemic' and 'argumentative' operations need to be present in science classrooms and science teachers need to be able to promote such ways of talking science.

The notion of 'epistemic operations' was also utilised by Jiménez-Aleixandre, Buggalo-Rodríguez and Duschl (2000), who examined the discursive interactions of a group of high school students that were taught science by the same teacher over 6 lessons, of which the last two were based on argumentation. Jiménez-Aleixandre et al. found that during the last two lessons, students engaged in 'true dialogue' were the teacher posed questions with no definite answers, and 'cross-discussion' where the students' discussions took place without direct interference or influence by the teacher (Lemke, 1990), instead of the more traditional triadic dialogue or IRE that teachers and students have been found to engage in during science instruction. Moreover, these researchers identified 8 epistemic operations that they then applied to the classroom talk during the six lessons observed. These epistemic operations were induction; deduction; causality; definition; classifying; appeal to analogy, to exemplar/instance, to attribute, to authority; consistency with other knowledge, with experience, commitment to consistency, metaphysical; and finally, plausibility. Their results indicate that due to the nature of the content taught, students mainly used causality, (defined as looking for mechanisms or predictions) and the use of analogies in attempts to explain a phenomenon. Although Mason's (1996) and Jiménez-Aleixandre et al.'s (2000) studies provide a framework that is able to describe the epistemic discourse taking place in science classrooms, this was based on student discussions, mostly during group activities. However, as stated previously, the role of the teacher can be instrumental for the development of epistemic discourse since the students' talk has been found to be influenced by their teachers' talk (Gillies & Khan, 2009; Webb et al., 2006; Zeidler & Lederman, 1989). Thus, studies that provide insights to the epistemic discourse initiated by teachers need to be developed.

Science teachers' epistemic discourse was the focus of a study by Jiménez-Aleixandre, Mortimer, Silva and Diaz (2008) who utilised epistemic operations similar to those used by Mason (1996) for their analysis of classroom talk. Jiménez-Aleixandre et al. (2008)

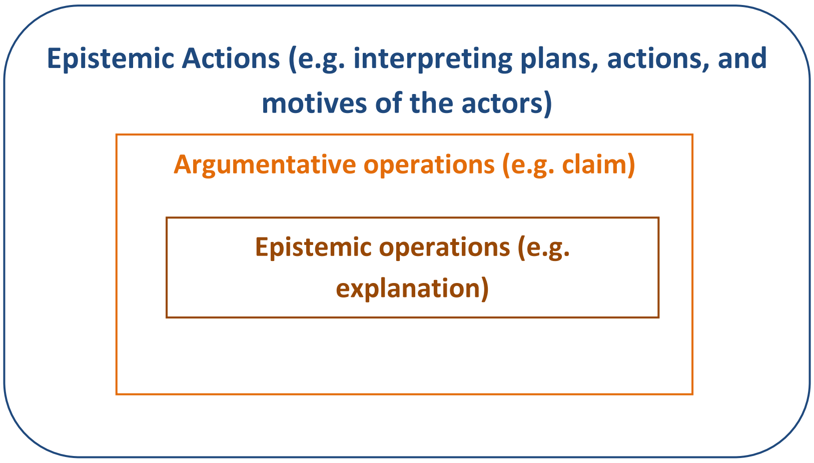
provide two analytical frameworks for the epistemic analysis of classroom discourse, the first for analysing and evaluating students' epistemic activities and the second for science teachers' epistemic operations. The ten epistemic operations likely to be used by science teachers, especially for the subjects of Physics and Chemistry on which the authors focused, were defining; describing; explaining; classifying; generalising; exemplifying; constructing arguments; appealing to analogies and metaphors; calculating; and, constructing narratives. The analysis of teachers' classroom talk based on epistemic operations presented by Jiménez-Aleixandre et al. (2008), emphasises the use of the epistemic operations of 'Description', 'Explanation' and 'Generalisation' as the way that teachers can help their students move from specific constructs to abstract constructs such as a model or theory of a class of events (e.g., from boiling water to absorbing heat to thermal equilibrium and breaking molecule bonds). Such analyses are important since students often are unable or have difficulties thinking about processes or concepts on a more general level and for instance, they tend to refer to all liquids as 'water' or to all gas as 'air'. What Jiménez-Aleixandre et al. (2008) seem to be missing is a more in-depth analysis of teacher discourse based on all of the epistemic operations they list and of ways in which these epistemic operations promote students' higher-order learning and engagement with epistemic discourse. In any case, the use of a framework of 'epistemic operations' could be one way to characterise classroom talk during argumentation instruction and identify those characteristics that are able to promote and establish epistemic discourse in the science classroom.

3.4 Identifying Epistemic Discourse Through 'Epistemic Operations'

The notion of *epistemic operations* that Pontecorvo and Girardet (1993), Mason (1996), and Jiménez-Aleixandre and her colleagues (Jiménez-Aleixandre et al., 2000, 2008) used to frame the analysis of discursive interactions is a way to organise and structure classroom talk in detail and in a manner that can portray the reasoning practices that take place in the classroom. Thus, *epistemic operations* as a way of identifying and characterising epistemic discourse are further explored in this section.

In the work of Pontecorvo and Girardet (1993) each utterance of the students' classroom talk was categorised in three different levels. Firstly, the students' discursive interactions were framed by the typical goals and procedures of the knowledge domain examined (history), e.g., the explanation of historical events, which the authors labelled as *epistemic actions*. Secondly, each utterance was categorised as an *argumentative operation*, which demonstrated the function of the utterance within an argumentative episode – that is, whether the students were engaging in making claims, concessions, oppositions, providing justifications, or counter-oppositions. Thirdly, the category of *epistemic operations* was utilised to denounce the cognitive function of the students' utterances.

Figure 3.3: Pontecorvo and Girardet's (1993) categorisation of the function of student discourse in history classrooms (with examples)



Based on the categorisation of discourse described above, and the discussion on epistemic practices and epistemic discourse presented in Section 3.3, there are two issues that need to be considered. Firstly, the difference between 'action' and 'practice', and secondly the distinction made between 'argumentative' and 'epistemic' operations. As discussed in the previous sections of this chapter, within this thesis science is framed based on the epistemic practices that characterise scientific endeavour. These epistemic practices, such as the construction, justification, and evaluation of knowledge claims, represent the 'epistemic actions' discussed by Pontecorvo and Girardet (1993) in historical contexts. The term 'practice' instead of action is used, firstly in order to be consistent with the literature reviewed in Section 3.1 (e.g. Kelly's description of epistemic practices) and secondly, because 'practice' is considered as the sum of a number of actions that contributes towards the same objective. For instance, the epistemic practice of evaluation could be operationalised through discursive actions such as contrasting differing views and/or making evaluative judgments about a piece of evidence. As a consequence, in an analysis of the epistemic features of classroom talk, the discourse taking place between teachers and students in the science classroom could be characterised firstly, by the specific epistemic practices (or actions as used by Pontecorvo and Girardet) in which they contribute, and secondly, by epistemic and/or argumentative operations.

The second issue for consideration is that of the distinction made between argumentative and epistemic operations. The epistemic operations utilised by Pontecorvo and Girardet (1993) were definition; categorisation; predication (or prediction); evaluation; and finally, appeal to analogies, examples, conditions, rules, motives, consequences/implications, authority, time, socio-cultural context, or spatial/temporal context. These where identified in fourth-graders' group discussions of a history topic. As mentioned in the previous section, Mason's analysis of fifth-graders' group discussions in a scientific context showed that these epistemic operations were not consistent with the talk that was taking place in her classroom, and thus Mason (1996) used a different list of epistemic operations which, according to her, it better reflected the explanatory and methodological procedures of science (see Table 3.2).

Argumentative operations were used to demonstrate the moves (supporting a view, opposing a view, providing justifications for a view etc.) amongst a group of students as they engaged in discussions about a topic. These argumentative moves might not be present in a teacher's talk as s/he engage in discussion with students. During an argumentation lesson, the teacher would present different arguments to the students (and thus attempt to engage them in the epistemic operation of 'Argument') in order to model the types of arguments the students should be creating and then, ask them to discuss the arguments presented or construct their own arguments and counter-arguments. Thus, the distinction made between argumentative and epistemic operations may not be as useful when exploring the classroom talk initiated by teachers in argument-based instruction. Additionally, the two studies by Mason (1996) and, Pontecorvo and Girardet (1993) have used argumentative and epistemic operations to analyse the classroom talk of *students* as they engaged in activities arguing about a problem. Yet, as the aim of this thesis is to focus on the teacher's discursive interactions and how s/he presents the epistemic nature of scientific practices to their students, the function of this talk would be expected to be different from that of the students' talk.

Conversely, argumentative operations could be considered as part of the discursive and reasoning practices of science teachers, that is, as part of the epistemic operations they use when talking with/to their students during argumentation lessons. For instance, the argumentative operation of 'justification', which is defined as 'any clause that furnishes adequate grounds or warrants for a claim' (Pontecorvo & Girardet, 1993, p.373), could constitute an epistemic operation – that is, a cognitive discursive action that provides reasons or grounds in support of a claim. This epistemic operation would not be specific to argumentation lessons but could be found in non-argumentation lessons as well, in the talk of everyday science teaching. What is more, the teacher would not be expected to use the epistemic operation of 'Application', defined as the 'action of applying generally newly learned knowledge' (Mason, 1996, p.415) as this would be an action that students would undertake based on new knowledge/information they acquired from their teachers. However, teachers would be expected to present an argument to their students, thus using the operation of 'Arguing', which is not part of either, the Pontecorvo and Girardet (1993) study or, the Mason (1996) study.

Another way to view at epistemic operations is through Ohlsson's (1996) work who also proposes the use of *epistemic operations or tasks* to examine the actions of teachers and students when they talk together. These are *describing*, *defining*, *predicting*, *exemplifying*, *explaining*, *critiquing (evaluating)* and *arguing*. Ohlsson (1996) argues that the importance of the epistemic operations he suggests lies in their ability to promote higher-order learning and understanding since 'collections of facts do not in and of themselves constitute understanding' (p.48). Ohlsson continues by arguing that 'abstract knowledge is the basis for understanding' (p.48) and thus, it is important to examine the operations of tasks that learners engage in whilst they attempt to make meaning of the facts presented to them and develop their higher-order thinking skills. Thus, compared to the list of epistemic operations provided by Pontecorvo and Girardet (1993) and Mason (1996), Ohlsson's list is more comprehensive as not only does it include the argumentative and epistemic operations of 'Arguing' but also the epistemic operations of 'Description' and 'Explanation' which are ways of talking that would be expected by science teachers. Nonetheless, Ohlsson's list of epistemic operations shows that it is not exhaustive, as he suggests, and that there could be additional epistemic operations used in science classrooms, such as compare and contrast, classifying or categorising, calculating and using analogies and metaphors (Collins & Ferguson, 1993; Jiménez-Aleixandre et al., 2000; Jiménez-Aleixandre et al., 2008). Other epistemic operations undertaken by science teachers could be the creation of models of phenomena and entities discussed in the classroom (Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999).

Overall, within this thesis, epistemic operations are defined as the discursive and cognitive operations undertaken by teachers or students, whose function is to promote the creation and development of knowledge and understanding, and are thus labelled as ‘epistemic’. Table 3.2 presents a synopsis of all the epistemic operations found in the literature with the inclusion of additional ones that might be present in argumentation lessons. The epistemic operations presented in Table 3.2 have a variety of complexity and uses in each domain of science and by individual teachers. Finally, it should be noted that as the notion of epistemic operations has not been applied to characterise the classroom talk of science teachers previously, especially in the context of argumentation lessons, it remains to be seen which types of operations are most frequently used in contexts where argumentation is utilised as a framework for teaching science and where it is not.

3.5 Conclusions

The emphasis placed on including NOS aspects in science education and the reconsideration of the role of evidence in science (Duschl & Osborne, 2002) has led to the creation of intervention studies that focus on promoting dialogic argumentation as a learning and teaching approach to science. These intervention studies are predominantly short-term and have shown to influence students’ conceptual learning positively in a number of studies (e.g. Venville & Dawson, 2010), but only a few have focused on the influence of argumentation on students’ understanding of the NOS (McDonald, 2010). As discussed in Sections 3.1 and 3.2, argumentation and epistemology are two interrelated fields and the interactions between them within science education need to be established. Therefore, more research needs to be conducted, especially longer-term studies, that closely investigate the implementation and effect of teaching science as argument, and the influence that this approach has for the development of students’ informed epistemological understanding.

Table 3.2: A synopsis of epistemic operations as reported in the literature

Pontecorvo & Girardet (1993)	**Ohlsson (1996)**	**Mason (1996)**	**Jiménez-Aleixandre et al. (2008)**	**Jiménez-Aleixandre et al. (2000)**	**Other**
	Describing		Describing		
Defining	Defining	Defining	Defining	Defining	
	Exemplifying				
Predicting	Predicting			Causality (Relation of cause–effect, looking for mechanisms, Prediction)	
	Explaining		Explaining		
Evaluation	Critiquing (Evaluating)				
	Arguing	Arguing (claim; justification; concession; opposition; counter-opposition)	Constructing arguments		
Categorising			Classifying	Classifying	
		Generalising	Generalising		
Appealing to analogies, conditions, consequences, implications, authority etc.		Appealing to evidence, experience, data, analogies etc.	Appealing to analogies and metaphors	Appealing to analogies, instances or attributes as a means of explanation	
			Calculating		
			Constructing narratives		
				Consistency with other knowledge, experience, commitment to consistency, metaphysical	Coordination of theories and evidence
					Modelling
					Compare and Contrast
				Plausibility	

The fact that a number of science teachers have been trained and supported in implementing argumentation in their science lessons as part of the T2L study provides a unique opportunity to examine the incorporation of argumentative activities in science lessons and their epistemic function.

Based on the review of the literature provided in Section 3.4, it is evident that there is not enough emphasis placed on analysing the epistemic discourse of science classrooms, and especially the discourse initiated by teachers. A detailed examination of the epistemic discourse that takes place in the science classroom is needed, to determine exactly which discursive actions or epistemic operations teachers do or could incorporate in their classroom talk to help students advance their conceptual and epistemic understanding. The analysis of classroom talk for its epistemic function could also provide an insight to which, if any, of the epistemic practices of science (e.g. construction, justification, evaluation) are presented in science classrooms through the teacher-initiated talk and which epistemic practices students engage in. Additionally, an investigation of the epistemic discourse that takes place in lessons that are not focusing on argumentation would provide a basis for comparison between the two ways of teaching science (argumentation-based and traditional approaches). Such comparisons would be helpful in determining the ways epistemic discourse differs or is similar to the 'ordinary' talk of science classrooms. What is more, comparing argumentation and non-argumentation instruction could provide an insight to the ways in which the epistemic nature of science is presented based on the two types of science instruction. Consequently, the first research question guiding this study is:

> **RQ1.** What are the epistemic features of science teachers' classroom talk during argumentation and non-argumentation activities?

Examining the epistemic characteristics of science teachers' talk during argumentation activities can help determine whether science teachers perceive argumentation as an epistemic practice and what is more, whether they are in a position to present it in such a way to their students as to help them develop an informed epistemological understanding. As previously mentioned, this thesis is formed and developed as part of the T2L project, which is working with teachers that attempt to develop their teaching practices to include more instruction in argumentation. Therefore, in investigating the epistemic features of science teachers' classroom talk, the teachers' discursive practices could also be examined to determine if argument-based instruction becomes part of their everyday science teaching. Thus, the second research question to be investigated in this thesis is:

> **RQ2.** Does science teachers' epistemic talk change as they participate in a professional development programme that aims to incorporate argumentation into their everyday practice?

To sum up, an exploration of the epistemic discourse of the science classroom as initiated by the science teacher, is a way to investigate the extent to which students are provided with opportunities to engage in epistemic discourse, and thus, to develop their epistemological understanding of science. This exploration can be achieved through analysing the classroom talk that is initiated by the teacher in terms of its epistemic function and the way that it represents the epistemic activities characteristic of the scientific enterprise, such as the construction, justification and evaluation of knowledge claims (Kelly, 2008). Moreover, the notion of 'epistemic operations', as summarised in Table 3.2, could be utilised as a framework for analysing the classroom talk of teachers during argumentation and non-argumentation lessons.

Besides investigating the ways in which science teachers present the practice of science through their classroom talk to students, the students' own classroom talk would need to be investigated to determine the extent to which the teachers' use of epistemic discourse influences the students' use of epistemic discourse in science lessons. Moreover, if the students' epistemic discourse is to be examined, then their ability to coordinate theory and evidence and their views on the role of evidence in science, is an aspect of the NOS that should also be taken into consideration. Examining the students' views on the nature and role of theories and evidence in science is needed since students will be engaging in argument-based instruction, which would require them to use evidence to support their views, counter-argue and apply criteria for evaluation of knowledge claims. The students' participation in such activities will depend on whether they are aware of criteria for evaluating the quality of evidence presented with, their views on facts in science and their perceptions of how they are used in scientific investigations. Therefore, the third and fourth research questions of this thesis, which focus on students, are:

RQ3. What are students' understanding of the nature and role of theories and evidence in science, over the course of a school year?

RQ4. What are the epistemic features of students' talk during argumentation instruction over the course of a school year?

The next chapter presents a summary of research on students' understanding of the nature and role of theories and evidence, to provide a background of what is already known about students' understanding of this aspect of the NOS.

CHAPTER 4

STUDENTS' CONCEPTIONS OF THE NATURE AND ROLE OF THEORIES AND EVIDENCE IN SCIENCE

4.1 INTRODUCTION

This study aims to investigate the epistemic features of science teachers' classroom talk during argumentation activities and the possible influence of this type of epistemic discourse on students' classroom talk and use of epistemic discourse. In this process, the students' views on the nature and role of theories and evidence in science may influence their ability to engage in epistemic discourse. Duschl (1990) points out that science education has been missing 'the chain of reasoning that has brought us to this point of understanding' in science (p.10). This kind of reasoning can be developed through the use of argumentation in the science classroom where students actively construct their knowledge through the creation of evidence-based arguments. Through argumentation students are required to deal explicitly with knowledge claims; they work in a context where a theory must be built and then adequately supported using the appropriate evidence. In this way, students engage actively in the process of justifying and evaluating knowledge instead of simply having to memorise the scientific content they are taught at school. Consequently, students may better realise the way in which theories are built and dealt with by scientists and how different propositions (evidence, claims, data and counter-arguments) interrelate with each other in producing an explanation of a phenomenon.

The first part of this chapter considers students' formal epistemologies of scientific theories and their function in the practice of science since this understanding may influence how students use theories and how they reason about them (Sandoval & Morrison, 2003). For instance, if students do not consider scientific theories an integral part of science they are likely to ignore them and consider as more important the facts they learn during science lessons. Students' perceptions of the ways in which evidence is utilised in science and the role of evidence in scientific investigations reflect on the ways in which students will subsequently use evidence during their own investigations and the criteria they will apply in evidence selection and evaluation. Therefore, the second part of this chapter is an examination of secondary school students' conceptions of the nature and role of evidence in science. Moreover, as part of the examination of students' understanding of scientific evidence, research looking into the students' practical epistemologies of evidence, that is the ways in which students use evidence and their ability to consider different sets of evidence to support an argument, is also reviewed.

4.2 STUDENTS' CONCEPTIONS OF SCIENTIFIC THEORIES

Harré (1984) maintains that 'theories are the crown of science, for in them our understanding of the world is expressed' (p.168). This statement mirrors scientific theories as central to the practice of science. Yet, as Dagher, Brickhouse, Shipman and Letts (2004) mention, 'scientific theories are perhaps the most misunderstood aspect of the nature of science often regarded as educated guesses, or highly tentative and easily dispensable explanations about phenomena' (p.735) instead of coherent and tested explanatory models of natural phenomena.

An extensive, naturalistic study of students' conceptualisations of scientific theories comes from Driver et al. (1996), who qualitatively explored students' images of science across different age groups (9, 12 and 16 years old). The authors created six probes in specific contexts that approximately 30 pairs of students from each age group had to discuss during an interview. In order to examine students of different ages the probes presented were designed to include the same science content accessible to all age groups. Driver et al. (1996) concluded that students have difficulties determining the role of theories in science and how theories are evaluated against existing data. In particular, scientific theories were viewed as taken-for-granted facts that did not need any further support by evidence, a view dominant especially among the nine-year olds. Some students had a more elaborated view of theories, by considering them as involving the correlation of variables. For example, when students tried to explain why a balloon with hot air blows up they stated that the heat makes the air inside the balloon hotter, which makes the balloon blow up, explicitly correlating the concept of temperature to the changing size of the balloon. Other students, especially 16-year olds, were able provide even more elaborated views on the nature of scientific theories and to consider them as models that correspond to the phenomenon under discussion. Driver et al. (1996) report that overall, older students demonstrated a more sophisticated understanding of scientific theories suggesting that students' understanding of the nature of scientific theories may improve with age and science instruction that allows for discussion and reflection in the science classroom.

Kang et al. (2005) present another naturalistic study using a large sample. These authors explored Korean students' NOS conceptions and reported that out of the 534 sixth graders, 551 eighth graders and 617 tenth graders participating in their study, less than 20% considered the purpose of science as creating explanations and even less were able to justify their answers based on a more sophisticated understanding of the NOS. Instead, almost half the students considered scientific theories as facts proven through experimentation and testing. Furthermore, a smaller proportion of students considered scientific theories as well-educated guesses. Only about 25% of students considered scientific theories as explanations, and even then, many of these students were found to have misconceptions of the notion of explanation when interviewed, which they viewed as description rather than involving causality. The Kang et al. (2005) study did not show any significant differences between the three age groups as the Driver et al. (1996) study showed, which according to Kang et al. could be attributed to the different cultural background of the students in the two projects or to the different research methodologies adopted.

Meyling (1997) reports on the way in which students relate theories to other scientific constructs such as hypotheses and laws. Meyling (1997) examined German secondary school students' conceptions of several scientific constructs such as scientific laws, theories, models, and the pathway of scientific discovery. The results of this study showed that Grade 10-13 students provided a linear account using concepts like observation, hypothesis, laws, theories, experiment. In particular, the majority of the participating students put these concepts in the following order: Experiment-Observation-Hypothesis-Theory-Law. This linear representation of the 'Pathway of Scientific

Discovery' places scientific theories a step before scientific laws, depending on whether, and the extent to which, the theory can be proven true. Such views mirror an inductive way of reasoning based on a realist perspective since the more proof there is of theories, the truer they will be.

One of the first studies to focus on improving students' conceptions of theories in science is presented by Carey et al. (1989), who report an intervention aiming to enhance seventh graders' understanding of scientific theories, experimentation, hypotheses and the scientific practice. This study started with a week-long introductory instruction on issues such as where students' ideas come from; the different ideas students have when asked to do the same task; and the difference between observations and inferences through a 'black-box' activity. The first week was followed by a two-week specially designed session on the introduction of the methods of science based on a unit on yeast. The results, coming from pre- and post-interviewing 27 of the 76 participants, showed that students did not have an adequate understanding of the nature and role of theories, hypotheses or experimentation. They found that pupils understood the purpose of science as 'discovering facts, making inventions and developing cures' (p. 523). Even after the two-week intervention unit, the change towards an adequate epistemological understanding was marginal. The small improvement of students' understanding of theories, experimentation and hypotheses in the practice of science, led Carey et al. (1989) to argue that the processes of science are not taught within a context that promotes the active construction and evaluation of students' own ideas regarding natural phenomena. Therefore, students form an inductivist view of science, characterised by a perception that science is a process of fact accumulation to reach the ultimate truth.

Sandoval and Morrison (2003) further explored students' understanding of scientific theories using the same interview schedule developed and applied by Carey et al. (1989). The eight student participants in Sandoval and Morrison's study were ninth graders who were given the opportunity to engage in a computer-supported learning environment, which encouraged group discussion, evaluation and explanation construction, features which according to Carey et al. (1989) are essential for the development of an adequate understanding of the role of theories within the scientific discipline. Yet, Sandoval and Morrison (2003) report that even though students were encouraged to discuss alternative explanations using a variety of evidence before deciding which theory is the best, they did not seem to realise the role of, and interplay between, scientific theories and evidence. Another alternative conception of scientific theories elicited by Sandoval and Morrison (2003) was that of theories as hypotheses that have been repeatedly proven, which once again demonstrated students' inductive view of science, where experimental results are used to prove hypotheses/theories as true.

Overall, secondary school students seem to have difficulty conceptualising the explanatory nature of scientific theories, which they consider as hypotheses or tentative guesses in need of testing and experimentation to be proven true. Moreover, students are not able to distinguish between fundamental concepts of the scientific practice, such as scientific theories, hypotheses, laws and facts. These alternative conceptions seem to be difficult to change since even with intervention studies, the change reported is minimal. Yet, the Driver et al. (1996) study provides evidence that suggest that students' alternative conceptions of scientific theories show some improvement with age and the appropriate science instruction, which would suggest that there needs to be more research on ways of developing students' conceptions of scientific theories during the secondary school age, and of framing the appropriate science instruction to achieve this change.

4.3 Students' Conceptions of the Nature and Role of Evidence in Science

The nature and role of evidence in the practice of science is another aspect of the epistemology of science that students need to understand and apply in their own investigations and arguments. In particular, the issues to be presented in this section include (a) the ways in which students deal with evidence in science lessons, (b) the criteria they use to choose between evidence to support or reject a claim and finally (c) the level of importance they attribute to the use of different types of evidence.

4.3.1 Use of evidence

The ways in which students may use and consider evidence in scientific investigations varies considerably. Chinn and Brewer (1993) argue that students are not always able to successfully consider evidence, especially when the evidence is contrary to their beliefs maintaining that when students are presented with disconfirming evidence, they react in one of seven distinct ways. Students can simply *ignore* the anomalous data or they may consider it at first, but eventually *reject* it attributing faults to the data collection process. Students *exclude* anomalous data when they think evidence is simply not relevant to their theory or explanation and consequently, not worthy of consideration. Moreover, students presented with anomalous data may choose to *postpone thinking about them* believing it is possible to incorporate these anomalous data into the theory later on. Thus, they do not need to change their theory or ignore the data. Additionally, students may attempt to *reinterpret* the data given, so as not to have to change their theories. In other cases, students may *change only peripheral parts* or conditions of their theory to accommodate the disconfirming evidence instead of changing their entire theory. Finally, the most advanced response to anomalous data, and the desired outcome of most science instruction, is *theory change* where students evaluate their theory against the evidence and decide to reject it and adopt a new theory able to explain the anomalous data.

A study which empirically demonstrates that young students have a range of reactions to disconfirming evidence was conducted by Mason (2001), who investigated how eighth graders dealt with conflicting evidence and alternative explanations in a scientific and a non-scientific context. Mason (2001) categorised the participating students' reactions to anomalous data in 24 categories, which were analogous to the types of responses suggested by Chinn and Brewer (1993). Taken together, the results of these two studies show that theory change is not an easy task for students, especially when they currently are learning in environments that do not provide many opportunities for dealing with conflicting evidence and alternative viewpoints (Lemke, 1990). However, through argument-based instruction, which is build on a consideration of alternative viewpoints and the use of conflicting evidence, students are provided with learning environments where divergent views and conflict are present. This way of learning science can be beneficial for developing the students' ability to use evidence and what is more, coordinate this evidence with the theories/claims they are attempting to build their arguments on. Providing students with the 'right' explanations without a discussion of the ways in which such explanations have been formed and supported leads to the development of a distorted view of scientific knowledge and practice, especially the important role evidence has in empirically supporting scientific explanations and in facilitating the creation of new explanations.

4.3.2 Coordination of Theories and Evidence

Science can be seen as a continuous process of developing and evaluating scientific theories (Duschl, 1990). In this process, the nature and role of evidence is central. Scientists use the evidence they obtain to refine and improve a theory or to reject it. Research on students' ability to differentiate between theories and evidence and of the coordination between the two varies. On the one hand, Kuhn, Amsel and O'Loughlin (1988) argue that young children are unable to differentiate between theories and evidence. Instead, students often interpret the same evidence in different ways, depending on the theory. On the other hand, there are studies that show that even primary school children are able to grasp the relationship between theory and evidence, when given the appropriate support and guidance. In particular, Sodian et al. (1991) examined elementary school students' ability to differentiate between hypothetical beliefs and evidence through two studies and concluded that students are able to make these distinctions. During the first study, first and second graders were presented with two competing hypotheses and asked to select a test to choose the best between the two hypotheses. The second study required participants to go through the same process of choosing between two competing hypotheses, but this time based on their own tests. In both studies, students seemed able to differentiate the notions of hypothesis and evidence, and were able to think of ways to test a hypothesis.

Furthermore, Samarapungavan (1992), who studied first, third and fifth grade students' reasoning skills during theory choice tasks, concluded that even first graders could apply certain meta-conceptual criteria when choosing between competing theories. The criteria of theory choice explored were the empirical and logical consistency of the theories with the evidence presented, the range of explanation each theory provided and finally, the ad-hocness of each theory, which determined whether the two theories needed any auxiliary assumptions to be true. Children in all grades did very well choosing the theory that was consistent with the empirical evidence presented and tended to choose the theory that accounted for more observations than its competing theory. Samarapungavan (1992) argues that children's ability to reason based on the four meta-conceptual criteria mentioned above vary according to their content knowledge, grade and degree to which competing theories contradict or challenge students' prior beliefs. She also acknowledged that although children are able to use evidence in support of a theory there are more complex relationships between evidence and theories that young students may not be in a position to understand.

The study by Driver et al. (1996) also investigated students' ability to coordinate theories with evidence. They examined the coordination of theories and evidence in a range of ages and through two different topics. Students had to choose the best explanation and support it using the evidence they thought that were most appropriate. Overall, most students of this study, and especially in the older age groups, seemed to do well in distinguishing between the explanation and the evidence that supported or rejected that explanation and were in a position to evaluate the theories presented to them. Yet, there were cases where students were not able to coordinate theories and evidence. In other cases, students preferred to use their familiarity with the topics investigated or their prior knowledge to select an explanation rather than considering empirical evidence to inform their theory selection and evaluation. This would suggest that students deal with evidence in different ways and often they do not realise that evidence need to be used to support their views. Therefore, science instruction needs to include instances of explicitly considering the evidence students produce in their investigations. Students need to be provided with opportunities to build on that evidence in order for them to realise how and why evidence is important for the practice of science. Such evidence-based activities, are part of teaching science as argument, which would suggest that students engaging in argumentation would be in a better position to coordinate theory with evidence than students engaging in content-based instruction which only teaches them the facts of science, without any consideration of the link between these facts and the major ideas of science, or the way in which these facts have come to be considered as common knowledge.

4.3.3 The Role and Nature of Evidence in Scientific Investigations

Students' perceptions of the role of evidence in science was part of Jeong, Songer and Lee's (2007) study, who examined the 'evidentiary competence' of 40 Grade 6 students. According to Jeong et al. (2007), students need to have 'evidentiary competence', which is defined as 'the concepts and reasoning skills required to collect good, reliable, and valid data and to organise and interpret them up to a point where they can be readily used for evaluating theories and explanations' (p. 76). They used a questionnaire of multiple-choice and open-ended questions designed to evaluate six aspects of students' ability to plan, collect and interpret data. In particular, for the planning process students' ability to understand that knowledge claims need to be supported by empirical evidence was examined, as well as whether students realised that evidence need to be relevant to the claims investigated. For the data collection process, students were asked to plan their own investigation in order to assess their understanding of the need for objective and unbiased data and of the need of replicability of evidence. Finally, for the third stage of a scientific investigation, which involved the interpretation of data, this study explored students' ability to interpret examples based on a knowledge claim as well as identify patterns from tables and graphs.

The results of this investigation showed that half of the participating students suggested planning an investigation to collect empirical data to resolve a problem presented to them, recognising the need to use evidence for making an informed decision. Yet, the other 50% of the students preferred to resort to other sources of knowledge such as the authority of a teacher or a doctor, a choice consistent with the way that school science is practised where the teacher provides the correct answers and scientific content for students to learn. Another important finding was that students' ability to determine the relevancy of data needed for a specific investigation was limited in this age group. Jeong et al. (2007) conclude that even though students seemed to have an 'intuitive understanding' of scientific justifications, this understanding was not elaborated in any way. The study suggests that a more explicit attention to the use and role of evidence in scientific investigations is needed if students are to develop an appreciation for the nature and role of evidence in science.

The study of Driver et al. (1996) presents similar results to Jeong et al.'s study, not only for the younger participants but for the majority of the older students as well. Driver et al. (1996) investigated students' ability to provide evidence in support of a claim by asking them to explain the reasons for accepting as true statements such as 'the Earth is round like a very large ball' and 'a bulb in a circuit lights because electricity goes from the battery, through the wire, and to the bulb' (p.96). Most students used direct perceptual evidence to justify their beliefs and others based their responses on authority figures as science teachers. Yet, other students, mostly the 16 year-olds, were able to go beyond that and provide evidence drawn from inferences, which suggest a more advanced understanding of the use of evidence in scientific practice. Moreover, even though older students were better able to provide more complex answers for their warrants for belief in the two contexts, these answers accounted for only 40% of the total warrants offered by the 16 year-olds. This finding would suggest that students often do not realise the need to provide comprehensive reasoned arguments in support of their beliefs and, instead, prefer to appeal to authority or simply citing one or two pieces of evidence. Hence, there is the need to be taught explicitly how to construct arguments and use evidence to support or reject claims.

Students' understanding of the sufficiency and relevancy of evidence to the creation of evidence-based explanations was further explored by Sandoval and Millwood (2005) through an experimental study. Specifically, these researchers explored the ways in which 87 high-school biology students constructed written arguments in groups using a specially-designed software for argument construction. Students were given large sets of data on two natural selection topics, which they had to use to resolve a problem. The authors analysed the quality of students' final written arguments based on the conceptual quality of the claims made, the sufficiency of the data used to support claims, and the rhetorical references students made to evidence in support of a claim. Sandoval and Millwood (2005) found that when the students' claims were not conceptually challenging, students seemed able to cite particular key data to support their claims as well as sufficient evidence. However, the ability to use sufficient evidence was not present in cases where more complex links between data needed to be made. Although students often looked at different sets of data when exploring the problem, they did not include all the data in their arguments demonstrating the importance students gave to providing an answer in contrast to showing, through the use of data, how they came to believe that their answer was the solution to the problems presented to them.

Another finding is that students seemed to consider evidence as 'self-evident'. Even when students included data in their arguments, they often did not make any explicit connections between the data and their claim. Sandoval and Millwood (2005) comment that such omission of reference to specific evidence could be due to the students' understanding of data as absolute and objective information that can only be interpreted in one way. Alternatively, they mention that the view of evidence as self-evident that their participant students seemed to hold, could be the result of the fact that all students were in possession of the same sets of data so citing a particular graph would be enough and no further elaboration of the information given by that graph would be necessary. Finally, the authors claim that the self-evident nature of evidence presented by students could suggest an inability on the part of the students to differentiate between claims and data, which is a necessary condition for successful coordination of theory and evidence although, as mentioned in Section 4.2.2, students have been found to be able to make such distinctions.

4.4 Some Conclusions

In current science classrooms where science instruction mainly emphasises the content of science, students often develop misconceptions about the NOS, including the purpose of science and the nature and role of scientific theories and evidence. Students view scientific knowledge as absolute and true and scientific theories as tentative claims that need to be investigated and proven to become facts. It is worth considering that the everyday meaning of the word ‘theory’ may well influence students’ understanding of scientific theories and the way they use theories and evidence in scientific investigations. Students’ understanding of the everyday meaning of ‘theory’ interferes with its scientific meaning (Dagher & BouJaoude, 1997; Solomon et al., 1996), which makes the transition from the everyday to the scientific conception of ‘theory’ even more difficult.

Moreover, it seems that students confuse concepts like scientific theories, hypotheses and laws and often use these concepts interchangeably (Meyling, 1997; Sandoval & Morrison, 2003). Additionally, even though students at the secondary school level are able to make the basic distinction between empirical evidence and the theories it supports (Driver et al., 1996), students demonstrate an array of approaches to handling theories and evidence. To some extent, younger students have more difficulty dealing with evidence and considering the relation of any given evidence to a particular theory or explanation. The research reported by Driver et al., Sandoval and Millwood, and Jeong et al. suggests that students are able to coordinate theory and evidence on a basic level, but they are missing a deeper understanding and appreciation of the nature and role of theories and evidence for scientific investigations. This ability combined with Kuhn’s (2009) assertion that young individuals need to be introduced and trained into ways of reasoning would suggest that science educators need to find ways in which students at the secondary school level develop their potential and advance their reasoning and arguing skills.

Furthermore, several alternative conceptions that students hold come from both descriptive studies, such as the Driver et al. and Jeong et al. studies, as well as intervention studies as those by Carey et al. (1989), Sandoval and Morrison (2003) and, Sandoval and Millwood (2005). These intervention studies provided students with opportunities to construct their own knowledge of the issues investigated as well as engage in dialogic activities. Yet, the difference between the pre- and post-testing results of students' understanding of the NOS aspects investigated was minimal. Thus, although Sandoval and Morrison (2003) argue for the importance of the talk that takes place during inquiry-based activities, this talk needs to be structured in such ways that will promote the explicit attention to evidence and the epistemic justification that is required for the construction of knowledge. Students are able to use evidence to support a claim but this ability varies considerably since it is dependent on students' perceived need for using evidence to support ideas and their understanding of the criteria for evidence selection and evaluation (Sandoval & Millwood, 2005). Thus, attempts to improve students' epistemological competence should draw students' attention *explicitly* to the role and nature of theories and evidence in scientific investigations as suggested by research on improving students' understanding of other NOS aspects (Abd-El-Khalick, 2010). The use of argumentation activities in the science classroom provides students with an opportunity to familiarise themselves with the use of scientific evidence for the creation and support of scientific theories, and could be a way to advance students' understanding of the nature and use of evidence in science.

To sum up, the use of argumentation as a dialogic and reasoning activity that can promote students' conceptual and epistemic understanding of science was supported in Chapter 2. Moreover, in Chapter 3, argumentation was presented as an essential process of the epistemic practices of science. The epistemic nature of argumentation is the focus of this thesis and will be explored from two perspectives. Firstly, the ways science teachers participating in the T2L project implement argumentation through language will be explored. Secondly, the epistemic features of teachers' and students' classroom talk will be compared to determine what aspects of the teachers' classroom talk may enhance the students' epistemic discourse. The next chapter lays out the methodological considerations that an investigation of classroom talk aiming to answer the four research questions posed in Section 3.5 needs to address.

CHAPTER 5

METHODOLOGY

5.1 THE RESEARCH QUESTIONS

This thesis focused on the investigation of classroom talk during argumentation and non-argumentation instruction as a way to explore the extent to which epistemic discourse developed in these lessons. In particular, the role of the teacher and the particular ways in which different teachers implement argumentation, were explored. Moreover, the influence of teacher talk on students' understanding of aspects of the NOS such as the nature and role of theories and evidence in science, and of the characteristics of their own classroom talk were investigated. The research questions guiding the present study were:

- **RQ1.** What are the epistemic features of science teachers' classroom talk during argumentation and non-argumentation activities?
- **RQ2.** Does science teachers' epistemic talk change over time as they participate in a professional development programme that aims to incorporate argumentation into their everyday practice?
- **RQ3.** What are students' understanding of the nature and role of theories and evidence in science, over the course of a school year?
- **RQ4.** What are the epistemic features of students' classroom talk during argumentation activities over the course of a school year?

In order to provide answers to the research questions, a research methodology, which was suitable and able to assist towards the achievement of the study's objectives, was needed. The following section includes such an exploration of methodological issues and makes the case for adopting an exploratory case study design based on a qualitative methodology for designing and implementing this study.

5.2 A Qualitative Perspective on Research

The aim of this thesis is to provide a detailed, in-depth characterisation of the classroom talk that took place during argumentation and non-argumentation lessons so as to identify the extent to which 'epistemic discourse' takes place during these lessons. Moreover, students' views of theories and evidence in science and the students' own classroom talk are investigated to acquire a detailed picture of the classroom talk and practices of science classrooms. The need for detailed accounts of epistemic discourse, which as discussed in Chapter 3 are limited, leads to the adoption of a qualitative approach to research. Aikenhead (2006) maintains that qualitative approaches in science education, working within an 'interpretative' or 'social constructivist' paradigm (Creswell, 2009; Merriam, 1998), focus not only on assessing students' NOS ideas but also on understanding them. In this thesis, the processes on which focus is placed are the discourse between teachers and students, with a particular interest in the epistemic function of this discourse, when argumentation is utilised in teaching and learning science.

Moreover, emphasis is placed on the role of the teacher in initiating and sustaining epistemic discourse during science lessons. Determining the underlying epistemological assumptions that science teachers carry in their classroom talk and exploring possible connections to the students' epistemological sophistication is a process that requires the collection of rich information about both the teachers and their students. These aims can be achieved through conducting research within a qualitative, interpretative paradigm, which places emphasis on the processes rather than the consequences of the situation observed, and allows for the production of detailed accounts through a closer and in-depth exploration (Burns, 2000; Creswell, 1998; Yin, 2003).

The interpretative research paradigm focuses on the construction of knowledge with a distinctive commitment to the subjective nature of human experience, which influences the way knowledge is constructed and validated (Cohen & Manion, 1994). Within the boundaries of the interpretative framework, knowledge is recognised as subjective and observations are thought to be 'theory-laden' (Hanson, 1958), rejecting the objectivity supported by positivist perspectives on the creation of knowledge. Within the social sciences, positivism is a theoretical perspective that attempts to provide explanations of the social through methods that draw on the empiricist approaches and values of the natural sciences and quantitative methodologies (Benton & Craib, 2001). The use of a qualitative methodology for this research project is seen as a way to move beyond positivist perspectives that aim to construct 'objective' knowledge (Miller & Glassner, 2004).

The view adopted here considers the influence of the participants in the resulting outcome and acknowledges the power that the participants' language, history, culture and knowledge have in the process, analysis and outcome of the situations observed (Creswell, 2009; Gubrium & Holstein, 2003). Thus, the outcomes produced as a result of this study are contextual, in the sense that they cannot be generalised to form conclusions about all teaching of science as argument and about the ways that all students come to learn to 'talk science' (Lemke, 1990) and engage in epistemic discourse. However, the outcomes of qualitative studies in general, and this qualitative study in particular, are still significant since qualitative research methodologies provide the ground for presenting the participants' perspectives on the issues explored. For instance, in exploring the teachers' classroom talk through a qualitative perspective provides the opportunity for the teachers to offer information for the reasons that guide their discursive actions during teaching, their views on teaching science or on their students. Based on these perspectives and insights, possible explanatory hypotheses for the ways in which epistemic discourse advances in the science classroom may be created, which would not be possible to provide based on quantitative methodologies.

Cohen, Manion and Morrison (2000) support the view that an intention to understand the ways in which individuals within a context perceive the world and themselves can be approached both through a quantitative and qualitative perspective simultaneously. What is more, Hammersley (1996) argues for 'complementarity' as an approach to social science research that utilises both the qualitative and quantitative paradigms, which complement rather than contradict, each other. Thus, the adoption of a qualitative methodology to conduct research in the social sciences does not reject the possibility of utilising aspects of quantitative methodologies, such as quantitative data representation (Creswell, 2009; Gorard & Taylor, 2004; Hammersley, 1995). Moreover, qualitative and quantitative approaches to research could be viewed on a continuum, with terminology such as less, more, fewer and unique, utilised to provide techniques for describing qualitative data, especially when comparisons are made (Gorard & Taylor, 2004).

The quantification of qualitative data can be a useful indicator of dominant themes within the data collected for this thesis (Creswell, 2009) that can contribute towards answering the first, second and fourth research questions posed, which explore the epistemic discourse of teachers and students. These main themes, identified through quantitative means such as counting how many times an instance appears in a teacher's classroom talk, can then be used to start exploring the underlying reasons and patterns that lead to the more frequent presence of some themes over others. In this way, the contextual nature of the data collected is not lost whilst a greater amount of data can be considered.

5.2.1 Ontological Position

Within the non-positivist paradigm adopted as a framework to guide the design of this thesis, a critical realist position is taken, which recognises the existence of an external, yet independent, reality. 'Transcendental realism', a form of reality, which recognises the social influences upon creating knowledge, moves away from empirical realism, which signifies observational evidence as the core basis for belief (Bhaskar, 1978). Bhaskar's conceptualisation of reality claims to provide solutions to the problematic issues of defining reality in a post-positivist world and creating an ontological construction of knowledge, which corresponds to the issues of subjectivity and the need for interpretation addressed by the interpretative paradigm. As Benton and Craib (2001) state, 'critical realism differs from empiricism in theorising knowledge as a social process which involves variable "means of representation" (p.120). A critical realist position recognises that 'our knowledge of reality is always laden with some conceptual framework and is not assumed to be completely and exactly true' (Niiniluoto, 2002, p.91). In this way, critical realists move away from extreme notions of instrumentalism that reject any consideration of the existence of reality. At the same time, a critical realist perspective is able to maintain the importance of subjectivity and socio-cultural influences on the creation and establishment of scientific knowledge. In the context of this study, adopting a critical realist perspective would mean that the interpretation of the data collected are influenced by the ideas and beliefs of the researcher, and are in that respect subjective, and allow for further interpretations. What is more, the findings reported are based mainly on the teacher's perspectives, since it is the teacher talk that forms the basis for this study. At the same time, it is also acknowledged that what is reported in this thesis, is based on the reality of the classrooms investigated, which is to be presented in the following chapters through the extracts of talk provided.

5.2.2 Epistemological Position

The ontological position of critical realism adopted in his thesis, presupposes certain epistemological commitments on the ways in which knowledge comes to be. The first epistemological assumption, which characterises a qualitative methodology and a critical realist position, is the recognition and acceptance of the theory-laden character of observations. Observation is the main means through which scientists collect empirical evidence to support or reject a hypothesis. Yet, scientific observations are not to be considered as 'raw sense experiences' but rather as '*theory-laden'* activities (Hanson, 1958). Accordingly, an account of what is observed provided by researchers cannot be considered as truthful representations of reality, but as accounts which are interpretative and viewed through the researcher's beliefs, knowledge and experiences.

Another epistemological assumption of qualitative methodologies is the socially constructed nature of scientific knowledge. Scientific practices are undertaken in social contexts and the norms and practices of each scientific community are determinant factors on the formation and progression of scientific knowledge (Kuhn, 1962). According to Kuhn (1962, 1970), science is a discontinuous process of either normal or revolutionary science – paradigms, which are not commensurable since each paradigm is based on different theoretical values and assumptions that lead scientific investigations. Consequently, scientific knowledge is socially constructed, a characteristic that has implications for the degree to which it can be considered objective and reliable.

To overcome the problem of subjectivity, scientists need to place more emphasis on the nature and role of evidence. Chalmers (1999) states that epistemological questions deal with 'how scientific knowledge is vindicated by appeal to evidence and the nature of that evidence' (p. 213). Data collected through a research project are considered as evidence in support of claims through a process of inferential thinking, and the inferential nature of observations, especially within a qualitative paradigm, should be acknowledged. Therefore, within this thesis, the conclusions to be made based on the findings reached are not to be seen as 'true facts' but as indicators of patterns and of relations that might exist between the issues discussed.

Overall, a qualitative approach to educational research, with elements of a mixed-methods approach, is considered as the most appropriate methodology for investigating the epistemic discourse that takes place during argumentation and non-argumentation lessons within secondary school classrooms. A qualitative exploration of argumentation-based classrooms may provide valuable information on teachers' interpretations of the epistemic and dialogic nature of argumentation, and identify the epistemic discourse that takes place during these lessons. Moreover, the detailed accounts of classroom discourse may help towards determining the factors that influence students' use of epistemic discourse and their understanding of the nature and role of theories and evidence in science, within a complex setting, such as a science classroom. The next section presents a methodological approach which supports the utilisation of a case study methodology for investigating the issues raised in this thesis.

5.3 Classroom-Based Research through Case Studies

Within the qualitative paradigm, there are a number of methodological frameworks utilised to provide detailed explorations of complex issues, such as ethnographic studies, action research and case studies. The ethnographic approach is characterised by Geertz (1973) as an intellectual effort to provide a 'thick description' of the object of study through gathering as much information as possible to create an explanation of what is observed and studied.

Merriam (1998) makes the distinction between ethnography as the product of a detailed exploration of a social event or an environment, and ethnography as the particular strategies and techniques employed in order to gather the data needed to produce 'thick descriptions' of events. The teachers participating in this study were part of a group of science teachers trained to use argumentation in their lessons, and therefore, the conditions for a naturalistic study, which are necessary for a purely ethnographic study, were not present. As part of the T2L project, there was an intervention taking place in the form of training to use argumentation and teachers sharing experiences within each school department, which influenced classroom instruction and diverted from the everyday situations of classroom life. What is more, the context of the T2L project in which the teachers participated, make action research unsuitable as a basis for the design of this study. Within an action research design the researcher has an active role in the creation, implementation and assessment of the research project (Freebody, 2003). Yet, the aim of this study is to explore how teachers' attempt to make argumentation part of their practice through their classroom talk, and how that attempt promotes or not epistemic discourse, without interfering with that process.

Even though ethnography or action research could not be utilised as approaches to the design of this study in order to answer the research questions posed, elements of an ethnographic approach can still be utilised based on case studies. Within a case study approach, the focus is placed upon a particular case, which is studied in depth (Wiersma, 1991) and a detailed account and thick description of classrooms, teaching practices and student behaviour can be obtained (Yin, 2003). A case study design is thought able to contribute towards the objectives of this study, by focusing on individual teachers as cases of investigation. As discussed in Chapter 3, the role of the teacher is considered influential in the development of epistemic discourse in the science classroom. Thus, teachers could be selected to act as cases and the classroom talk that they initiate can be investigated for its epistemic function.

5.3.1 A Case Study Design to Explore Epistemic Discourse

A case study is defined as an investigation of 'a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident' (Yin, 2003, p.13). The specific conditions that characterise the context of a case study are intrinsic to it (Freebody, 2003) and, therefore, cannot be differentiated or controlled as variables influencing the situation under investigation. As Freebody (2003) maintains 'people's practices and experiences in particular educational contexts have been described as displaying uncertain, complex, messy and fleeting properties, all of which can be meticulously accounted for through a case study methodology' (p.81). Case studies are considered appropriate for studying contemporary events in which the researcher has little control over, such as the events taking place in a classroom setting, and, when the focus of the investigation is the process of learning rather than the outcome (Burns, 2000).

What is more, case studies could constitute part of wider research projects, focusing on particular instances of an investigation. The 'particularisation' (Stake, 1995) that characterises case study methodologies is advantageous since it can provide opportunities for creating a comprehensive account of the case and provide information that would be otherwise difficult to obtain. A case study, as part of a bigger project, is the one reported in Chapter 3 by Tzou (2006). Tzou (2006) focuses on only a small part of the intervention that took place in the project reported in order to describe in more detail the ways in which teachers applied a framework on explanation-based instruction they were taught to use as part of the main project undertaken.

It should be noted that the conclusions drawn from a particular case are unique to that case and attempts to generalise to wider contexts are often problematic or disputed. Yet, the uniqueness that a case study might yield does not have to be considered as a disadvantage since, through the case study, the researcher has the opportunity to familiarise him/herself with the case under investigation and come to know it and present it as never before. As Stake (1995) stresses:

> 'the real business of case study is particularisation, not generalisation. We take a particular case and come to know it well, not primarily as to how it is different from others but what it is, what it does. There is emphasis on uniqueness, and that implies knowledge of others that the case is different from, but the first emphasis is on understanding the case itself' (p.8).

Conducting a case study research involves the observation and examination of the study whilst at the same time progressive focusing takes place. The act of progressive focusing is essential while the researcher interprets the events investigated and places meaning over them. As Merriam (1998) maintains, 'the design of a qualitative study is emergent and flexible, responsive to changing conditions of the study in progress' (p.8). As the case develops and more information is gathered, the focus of the case study might be differentiated from the initial intentions of the researcher and the design of the study may be altered to fit the new insights that interpretation of on-going data collected provides (Stake, 1995). Hence, the focus of investigation might shift becoming more specific or by looking at the case through a different perspective to the one initially set out to explore.

5.3.1.1 Descriptive, Exploratory and Explanatory Case Studies

There are different types of case studies depending on the aim of the investigation, the questions to be answered, and the control the researcher has over the case investigated. Yin (2003) mentions that based on these parameters, case studies can be descriptive, exploratory, explanatory or some combination of these types. Descriptive case studies are those which aim to provide a detailed description of an event, usually providing an historical account of it (Merriam, 1998). Exploratory case studies focus on answering ‘what’ questions with an emphasis on exploring an event with the intent to create further hypotheses for future investigation (Yin, 2003). Finally, explanatory case studies are those that aim to explain a phenomenon through its persistent and detailed observation.

Based on the provisions and restrictions of the main T2L study within which the present thesis stands, the type of case study employed in this thesis is an *exploratory case study*. Although the main T2L study is an intervention study aiming at embedding a dialogic practice within the school departments’ and science teachers’ practices, this study does not interfere with the plan of action of the teachers. On the contrary, this study wishes to provide a more detailed account of the classroom environment and, particularly, the classroom talk that takes place within the participating teachers’ argumentation and non-argumentation lessons. Thus, there was no experimental element to the design of the case study since there was no intention on the part of the researcher of intervening in the process of teaching and learning, besides the requirement that both argumentation and non-argumentation lessons are to be taught during the school year. Additionally, this study is not simply descriptive since providing a detailed account of the classroom discourse observed is not the sole purpose of this study. Rather, designing this case study as an exploratory case provides the opportunity to explore and analyse the epistemic nature of the classroom discourse as initiated by the science teacher, and to provide an account of the students’ views of the NOS and classroom talk.

5.3.1.2 Multiple Case Studies

In planning for case study research one has to consider whether to select a single case or a number of cases with similarities and/or contrasting differences for investigation. Selecting one of these two approaches often depends on the contexts in which the cases are situated. For instance, if an extreme or unique case is presented to the researcher then a single case study design is appropriate. However, when there are different cases that can be studied as part of a case study design that could be complementary or contradicting, a multiple case study design is suitable to be applied (Stake, 1995; Yin, 2003). For the purposes of the current study a multiple case study approach has been adopted. This approach to case studies is possible since there was more that one teacher working on the T2L project in four different intervention schools across London, which provided the opportunity to explore how different teachers in different school settings implemented argumentation and used epistemic discourse.

The use of multiple case studies is considered as a form of replication of the outcomes of a case study (Yin, 2003), allowing for a form of triangulation between the cases through the comparison of the different cases and search of common patterns within the data from each case (Freebody, 2003). Using evidence from multiple case studies to support the assumptions leading the study is a way to increase the robustness of the study (Freebody, 2003; Yin, 2003). Yet, it is acknowledged that the search for common features between the case studies selected does not result in a comparative case study design. The aim is not to contrast the case studies developed but to use the findings from them to create an account of the epistemic discourse that develops through argumentation and non-argumentation instruction, which can then be used as an illustration of ways that epistemic discourse can be established in science classrooms.

Overall, an exploration of science teachers' discourse during argumentation instruction and of the possible influence of argumentation on students' epistemological understanding and talk, requires a research methodology that allows for the collection of all the necessary data both from teachers and students as they interact within a unique, real-life situation, such as a science classroom. In order to provide answers to the first and second research question, emphasis will be placed on the teacher and the classroom talk initiated by him/her. The main producer of the epistemic discourse investigated is considered to be the teacher, as it is the teacher’s responsibility to plan and orchestrate the talk that takes place in the classroom and introduce his/her students to argumentation as a reasoning and discursive practice of science. Yet, classroom discourse is not produced solely by the science teacher, as it can also be the result of the interaction between teacher and students (Tzou, 2006) and this verbal interaction needs to be taken into account. Finally, the teacher profiles created can then be used in conjunction with data collected from students in answering the third and fourth research question of the study.

5.4 The Case Sample

5.4.1 Teachers

Taking into consideration that a case study should aim to maximise what can be learnt from a particular situation, the selection of the case needs to be ‘easy to get to and hospitable to our inquiry’ (Stake, 1995, p.4). Based on these criteria, the search for teachers willing to allow access to their classrooms for an extensive period of time can be quite demanding. The participants should be prepared to share more of their time with the researcher and allow for observations, not only of argumentation lessons, required because of their participation in the T2L study, but also of non-argumentation or ‘ordinary’ lessons. Therefore, the sample was based on a combination of convenience sampling and criterion sampling (Creswell, 1998). The decision as to which teachers should be approached was based on criteria such as whether a teacher was confident teaching while observed, had shown enthusiasm and commitment to the project and an interest in the use of argumentation for teaching and learning science, as judged by the T2L research team. These characteristics were displayed primarily by the lead teachers of the four intervention schools, who were more likely to be committed to the present study, as they had already shown interest in participating in the T2L project. Moreover, the lead teachers would be more accessible to the researcher as they had regular communication with the project team and had been attending the professional development workshops.

From the target population of the eight lead teachers participating in the T2L project, three teachers from two different intervention schools were approached for participation in this study in January 2009. However, due to personal reasons, two of the teachers from the same school withdrew from the T2L project, and consequently from the present study, at the end of the 2008-09 school year. Thus, a different teacher from a third intervention school was approached for participation in this study. This teacher was not one of the initial lead teachers at his school, although since the start of the T2L project, he had taken an active role in promoting and sustaining the implementation of argumentation lessons within his school department, demonstrating in this way the characteristics searched for in lead teachers as participants of this study. Consequently, two case studies are presented in this thesis, based on two science teachers. A male teacher in his forties with about 20 years experience in science teaching, who with one of his Year 9 student groups comprised the first case study, presented in Chapter 6. The second case study, presented in Chapter 7, focuses on a female teacher and one of her Year 10 classes. This teacher, in her twenties, with three years of teaching experience, was one of the lead teachers for the T2L project at her school. Further details of the two teachers are presented in Chapters 6 and 7 accordingly.

5.4.2 Students

The student sample was purposive in nature as each science teacher was asked to choose a representative group (gender, attainment, engagement) of four students from their respective classrooms that the researcher could observe using video-recording equipment for the whole duration of the study. The decision to focus on one group of students from each classroom instead of the whole classroom population was based on practical reasons. It simply was not possible to record all groups of students in the classrooms observed (4-7 groups of students were formed in each of the lessons observed). The criteria set by the researcher were based on mixed ability and sex, students that were accustomed to working and talking together, and finally, students that could work in the same group throughout the period of conducting observations. The judgment of which students meet the criteria set by the study relied on the teacher as s/he had a better understanding of the student population of the classroom observed than the researcher. Students were asked to work together for the whole duration of this study as to maintain consistency of the data collected. As a result, two groups of students became the focus students of this investigation. The two groups consisted of two girls and two boys each, who had worked together in pairs and groups before the study commenced. More details of the students are provided in Chapter 8.

5.5 Research Methods

Case study methodologies require multiple sources of data in order to provide the researcher with the information necessary for providing in-depth accounts of the two case studies developed (Stake, 1995; Creswell, 2009). A necessary number of research sources can be used for data collection as part of a multiple case study design such as documentation, archival records, interviews, direct observations, participant-observation, and physical artefacts (Yin, 2003). The research methods chosen for this study were (a) lesson observations focusing on the teacher and a group of students, (b) formal and informal interviews for both teachers and students, (c) field notes during lesson observations, and the collection of documentation that were thought relevant to the study such as lesson plans, worksheets and resources that the teachers were using in their planning and implementation of the lessons observed. These three research methods are further explored and explained in the following sections.

5.5.1 Participant Observation

One of the primary sources of data for qualitative research methodologies comes from fieldwork and direct observation of the events explored. As Bryman (1988) asserts 'the most fundamental characteristic of qualitative research is its express commitment to viewing events, action, norms, values, etc. from the perspective of the people who are being studied' (p.61), emphasising that the researcher has to actually see what the participants are seeing and experiencing. Moreover, Creswell (2009) maintains that qualitative researchers need to visit the context in which the phenomenon under investigation takes place as to understand it and gather the necessary information themselves. Therefore, going into the science classrooms of the two participating teachers and directly observing the teaching and learning that takes place, is one of the methods of data collection selected for this study.

There are two main means of collecting observational data, (a) ‘complete observer’ or non-participant observation and (b) participant observation (Merriam, 1998; Yin, 2003). The former involves observation of the events investigated, such as in a science classroom, during which the presence of the researcher is acknowledged by the participating teacher and students, although there is no active participation or involvement of the researcher in the lesson; s/he is acting as a mere observer of the actions taking place. Conversely, the latter type of observation assumes an ‘active’ role for the researcher during which the researcher may be considered as part of the process observed (Yin, 2003).

As part of the aims of this thesis, there was a need to explore how teachers and students acted and interacted in the classroom and analyse the classroom discourse produced with as little interference as possible on the learning environment set up by each teacher. Although the researcher attempted to take a passive and non-intrusive role during the lessons observed, it is acknowledged that the presence of the researcher in a closed space such as a classroom, can still influence the actions of teacher and students. Students could be distracted by the presence of an outsider in their classroom and are often too conscious of the presence of recording equipment, which results in behaviours that are not customary of the everyday classroom setting (Creswell, 2009). Moreover, the researcher could act only as an observer of the participating teachers and students without any involvement or participation since everything observed were documented based on the researcher’s interpretative frameworks, knowledge and understanding (Merriam, 1998). Therefore, participant observation was selected as the appropriate approach to documenting the events and the discourse of the science classrooms observed for this study.

To answer the first and second research questions, both argumentation and non-argumentation lessons were observed and video-recorded to capture the verbal and non-verbal interactions between the teacher and the students. Argumentation lessons focused on the practice of argumentation in different ways, varying in time, number of activities and topic investigated depending on the teacher’s objectives and planning. Each teacher was asked to characterise the lessons observed as argumentation or not, based on the activities or aims they prepared for their lessons. The focus of these observations was on the teacher and the discourse initiated by him/her. Argumentation was a new way of talking in the classrooms observed and therefore, it was the teacher's responsibility and task to introduce this way of talking to his/her students and help them appropriate this type of discourse into their classroom talk. Non-argumentation lessons were those in which the teacher had not included in his/her lesson plan any activities considered by them as argumentation activities. Recording non-argumentation lessons was important for getting an insight of the general practices of each science teacher, in addition to the lessons that s/he had been requested to prepare as 'argumentation lessons'. The selection of which Year group each teacher would be observed teaching was made by the teachers after discussion with the researcher. The selection was based on availability (what Year groups the teachers will be teaching during the data collection year) and whether the teachers would be able to teach argumentation lessons with the classes selected. Based on these two criteria, one Year 9 class and one Year 10 class were the classes selected.

To capture the detailed information needed to answer the fourth research question of this study, students were also observed as they participated in argumentation and non-argumentation activities. The student observations centred on students' discussions both between them, and with their teachers. The fact that both the teacher and a group of students would be observed during each lesson, meant that accurately documenting what was happening in the classroom, and especially what was said during these lessons, was a challenging task. To facilitate the creation of accurate descriptions of the lessons observed, video and audio recording equipment was utilised (Heath, Hindmarsch & Luff, 2010; Patton, 2002).

The use of video and audio-recording equipment is advantageous for this study since detailed collection of verbal data could be achieved and allow for the examination of 'ways in which knowledge is revealed, shared and embodied' (Heath, Hindmarsh & Luff, 2010, p.8) within the science classroom. One video camera focused on the teacher, his/her movement and verbal interactions in the class. A second video camera focused on the group of students observed in each class and their verbal interactions. The equipment utilised for collecting data from the groups of students in each classroom, included audio-recorders, one for each pair. The use of additional audio-recording equipment was decided after initial pilot observations revealed that when students worked in groups, the levels of noise in the room were such that a clear recording of the student talk from the video-recorder was not always possible. In each of the two classrooms observed, cameras were placed at one of the back corners of the room, near to where the group of students observed was sitting, but 'hidden' enough as to draw minimal attention.

The presence of video and audio-recording equipment in the classroom can be disruptive both for the teacher and the students. In the case of the teachers, the interference of equipment was minimal as both teachers were familiar with the presence of the camera during their lessons, from observations of argumentation lessons taught for the T2L study, during the previous school year. In the case of students, the Year 9 students observed were also familiar with the camera equipment as they were filmed while in Year 8 by a different researcher as part of the T2L project. However, the Year 10 students had not been filmed prior to this study. Therefore, the researcher and their teacher both thought appropriate and helpful to have some initial lesson observations video-recorded as to allow students to familiarise themselves with the situation before the actual data collection process took place.

5.5.2 Field notes and Documentation

To create the case studies of the two science teachers observed, the video-recorded observations were combined with additional data collected during and after the science lessons observed. These data included in situ field notes to complement the observations, with a particular emphasis on the classroom environment, comments on particular students or the topic taught, reflective comments of the teacher for the lesson observed, and any other information that the researcher considered relevant to the study. Choosing what is relevant at any point is, of course, a subjective decision, which constitutes part of the limitations of this study. Other data sources collected were the material that the teachers were using such as lesson plans, worksheets, PowerPoint presentations, diagrams and other pictures drawn on the board or presented to the students. This material was complementary to the primary source of data collected and was used to provide a comprehensive picture of the context in which the discourse was recorded (Cohen, Manion & Morrison, 2000).

5.5.3 INTERVIEWS

Interviewing is a well-known technique within the qualitative research paradigm through which insightful information on the subject under investigation may be gained. Interviews are able to 'examine the context of thought, feeling and action and can be a way of exploring relationships between different aspects of a situation' (Arskey & Knight, 1999, p. 32). In-depth and semi-structured interviews have been successfully used in the past to document students' conceptions of the NOS in different contexts and for different aspects (Carey et al., 1989; Driver et al., 1996; Lederman et al., 2002), empirically supporting their use in this research project. One of the main advantages of interviews is the detailed information that is possible to be obtained from participants (Arksey & Knight, 1999; Rubin & Rubin, 2005). Considering the interview as a 'negotiated text' (Fontana & Frey, 2005) where both parties are actively involved is another strength of in-depth interviewing. Particularly, the interviewer is in a position to ask for more details when necessary to make sure that the meaning ascribed to concepts and questions is shared. The detailed responses and the mutual understanding between the two participating members are essential for obtaining as much information as possible on the issues discussed.

5.5.3.1 Teacher Interviews

The semi structured teacher interviews utilised for this study focused on three major issues, (a) the teachers' understanding of the NOS; (b) the teachers' beliefs about teaching and learning in science; and, (c) the teachers' beliefs about the nature of argumentation within scientific practices, and of argumentation as a teaching approach to science education. Previous studies investigating science teachers' practices maintain that teacher practices should be discussed whilst taking into consideration the teachers' views of teaching and learning and their knowledge of the subject taught (Brickhouse, 1990; Grossman, Wilson & Shulman, 1989; Hodson, 1993; Lotter, Harwood & Bonner, 2007; Tsai, 2002). For instance, Lotter et al. (2007) report three case studies exemplifying the ways in which core beliefs of science teachers, who participated in a professional development program focusing on inquiry, influenced the teachers' ability and willingness to incorporate aspects of inquiry in their lessons. These conceptions were teachers' conceptions of science; their ideas about the purpose of education; their beliefs about their students and how they learn; and, the teachers' views on effective teaching.

Although Lotter et al.'s study focused on promoting elements of inquiry into teaching practices, their results are useful for attempts to incorporate argumentation practices into everyday science teaching since teachers are requested to take up a new practice, which is different from their customary teaching practices. Similarly, Tsai (2002) argues that science teachers' beliefs about the NOS and their views on teaching and on learning science are three interrelated constructs, and should therefore be investigated together. As a result, the teacher interview schedule was drawn up to address the above issues and capture the teachers' views on the epistemic nature of scientific practices and knowledge and also, their views on teaching and learning science in general, and using argumentation in particular.

The purpose of the interviews were not only to detect any changes in the teachers' beliefs of the issues explored as they engaged in teaching argumentation but also to provide the teachers with an opportunity to reflect on their practices and discuss any issues they thought relevant to learning how to teach science through argument. For that purpose, a semi-structured interview schedule was developed (Appendix A). The same teacher interview schedule was utilised for the first and second interview conducted. The interview schedule was piloted with a different teacher participating to the T2L project before it was used with the teacher participants of this study. The information obtained from the teacher interviews was used as a form of triangulation with the data collected from classroom observations. For instance, the teachers' views on the NOS as mirrored through their interviews was combined and/or compared with instances from the teachers' talk about the function of the scientific enterprise and the work of scientists.

5.5.3.2 Student Interviews

The student interviews were semi-structured and aimed at eliciting the students' views of the nature and role of scientific theories and evidence for the practice of science. The student interview schedule (Appendix B1) is a version of an interview schedule developed as part of the T2L project (Christodoulou, Osborne, Howell-Richardson, Richardson, & Simon, 2010), and it is based on a combination of approaches to qualitative interviewing for eliciting NOS conceptions, based on the work of Driver et al. (1996) and Carey et al. (1989) discussed in Chapter 4. The student interview was piloted with two students from the Year 10 group observed to ensure clarity of terms added to the initial schedule and test the duration of the interview. Students were interviewed individually and each interview lasted from 30 to 45 minutes.

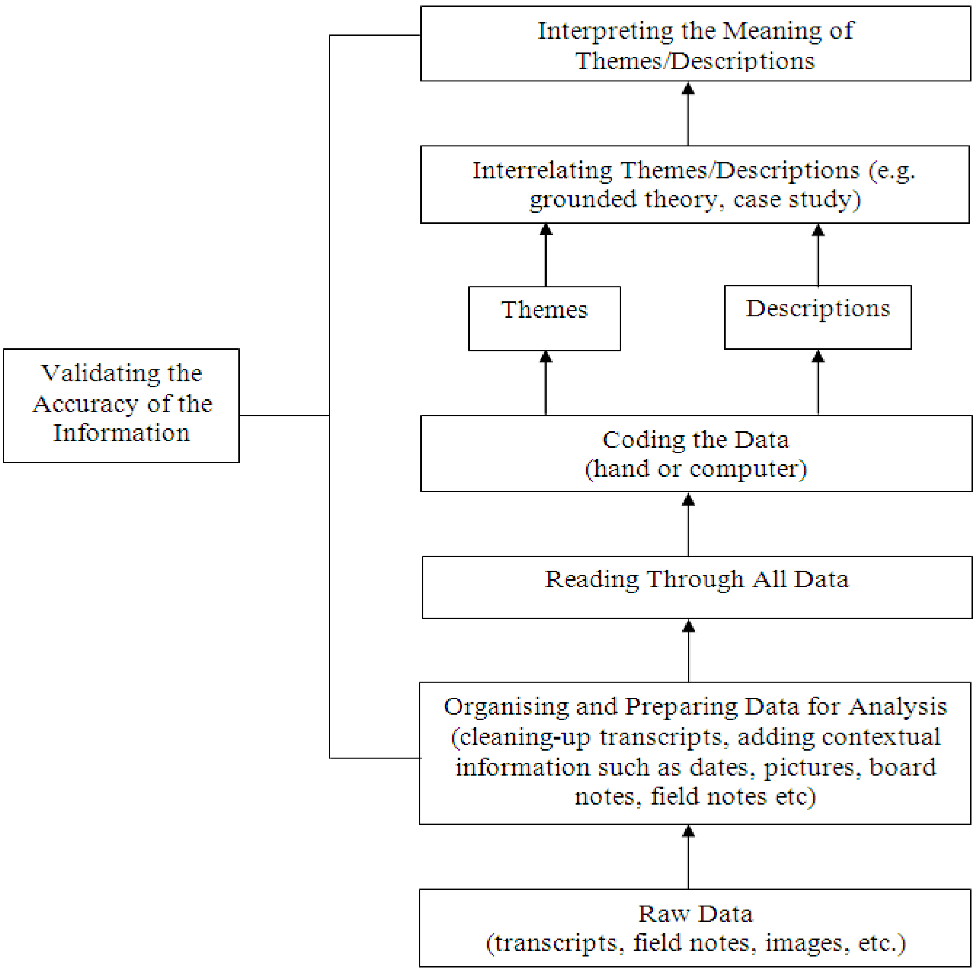
Since participants were young students, it was vital that a friendly and familiar environment was established to develop a mutual trust between the interviewer and the students (Fontana & Frey, 2005). The meaning of the topic under discussion was made as clear as possible and all necessary explanations and clarifications were given to the participants to establish a shared understanding of what was under discussion (Miller & Glassner, 2004). Moreover, the interview was based on a topic familiar to the students, so they could feel comfortable to participate in the interview and express freely their beliefs (Fontana & Frey, 2005; Miller & Glassner, 2004; Rubin & Rubin, 2005).

Limitations associated to in-depth interviewing concern time management, sample size and cost (Woodhouse, 2005). The time length of the interview must be appropriate, especially for secondary school students. Another issue to consider with conducting the teacher and the student interviews is the difficulties encountered for contacting and arranging meetings with the participants (Woodhouse, 2005). In the case of this study, arranging the student and teacher interviews at the start of the school year was problematic as the final stage of data collection for the T2L project coincided with the pre-test stage of the interviews for the current study. As a result, the first stage of interviewing with the teachers and students did not take place at the beginning of the school year but at the start of the second term, in January 2010. A detailed timeline of the data collection process for each of the two case studies is provided in Appendix C.

5.6 Analysis

The analysis of the multiple data collected for the two case studies was undertaken in several steps. Figure 5.3, presents the procedures undertaken for analysing the qualitative data collected for this study. Two main stages of data analysis took place. At first, analysis focused on the teachers, by transcribing the data from all the lesson observations and teacher interviews. The data from each teacher was treated collectively. That is, all relevant data from the teacher of Case Study 1 were transcribed, coded and analysed together before focusing on the data for the second teacher and Case Study 2. The second stage of analysis focused on the student data collected.

Figure 5.4: An inductive procedure for analysing Qualitative Data (as adapted from Creswell, 2009, p.185)



Initially, the teacher interviews and video recordings of lessons were transcribed verbatim. All transcriptions were carried out by the researcher and this process was considered as an initial familiarisation with the textual data. The second stage of analysis involved organising the data based on a chronological order from the first to the last observation, and adding any contextual information related, such as lesson plans, observation notes and pictures from the classrooms and whiteboards.

The transcription, organisation, coding and analysis of the data collected were undertaken using NVivo 8 (QSR, 2008). The use of software such as NVivo 8 for the analysis of qualitative data allows for greater consistency across the themes developed during the coding and analysing processes. Moreover, storage and retrieval of data from different sources becomes more convenient and less time-consuming than manual analysis techniques (Creswell, 2009). Finally, by using NVivo 8 there is the opportunity to conduct various types of searches within the data sets in order to determine whether there are any patterns between the themes developed (Bazeley, 2007).

The main techniques of data analysis utilised to make sense of the data collected from the two teachers and their classrooms, were thematic analysis (Boyatzis, 1998) and categorical aggregation (Stake, 1995). Thematic analysis involves the emergence of themes through the careful examination of data and it can be theory-driven or grounded in the data (Glazer & Strauss, 1967). Boyatzis (1998) provides three stages of coding development, (a) open coding aiming at identifying the codes/themes coming out of the data, (b) revision and refinement of the codes/themes created in order to create overarching categories from the initial themes/codes, and use these categories to look for patterns within the cases and finally, (c) establish some degree of reliability of the coding process through triangulation and code reliability checks. The specific procedures followed for each type of data collected are presented in more detail below.

5.6.1 Analysis of Teacher and Student Lesson Transcripts

The thematic coding applied to the lesson observation transcripts was theory-driven as it was based on the framework of epistemic operations presented in Table 3.2. Yet, the coding process allowed for the identification and creation of new thematic categories, wherever thought necessary, and their re-organisation in main themes and sub-themes. At first, three lessons were coded to identify the main themes and categories emerging from the data and in combination to the initial framework of epistemic operations. An ‘epistemic operation’ was identified based on the function that a particular utterance had. This could be a whole sentence, part of the sentence, or of a dialogic nature, including both the teacher and students, in order to capture the context in which the utterance was found. This approach is consistent with previous studies that have used the notion of epistemic operations to characterise classroom talk, using *idea units* which are defined as ‘the smallest units in which the discourse is analysed’ (Pontecorvo & Girardet, 1993, p.370).

These themes were re-organised and refined to create a final framework of epistemic operations (Appendix D1) that was then applied to all 25 lessons observed by both teachers. An inter-rater reliability check with an independent researcher took place. The independent researcher was provided with the definitions of each theme of epistemic operations and one lesson transcript to familiarise themselves with the process. Independent coding of one full lesson transcript and extensive extracts from three other lessons (out of a total of 25 lessons) was undertaken, to ensure that text in different contexts was coded (whole-class and group-work discussions/argumentation and non-argumentation lessons from both teachers). Initial agreement reached 69%. Differences of opinion were discussed and resolved with a final inter-rater agreement reaching 94%.

The classroom talk of students was transcribed and organised according to the teacher’s talk as illustrated in the example provided in Appendix E. To transcribe the classroom talk of students, the combination of the video and audio recordings of the students’ work was necessary. Initially, the talk from the first pair of students was transcribed and then, the talk from the second pair was completed. As this procedure required a great amount of time it was not possible to transcribe the students’ talk for all the lessons observed. Based on the time constraints of this study, it was decided that a full picture of the students’ participation in the lessons observed could be provided if only one of the two groups of students that participated in the study was presented. As a result, only the information obtained from the students of the first case study will be presented (Chapter 8). The transcripts of students’ talk from two of the six argumentation lessons observed for Case Study 1, were used to develop the coding framework of students’ talk. A process of open coding of the student talk transcripts in two of the argumentation lessons was used to identify all the discursive actions in the students’ talk. Then, these epistemic operations were refined and reorganised before a second round of coding was applied in all six argumentation lessons using the refined framework. This framework was based on the epistemic operations identified in the teacher talk, discussed above, for which a reliability check was already conducted, as presented above, and thus, further reliability checks were not undertaken. The epistemic operations found in the students' talk are presented in Appendix D2.

5.6.2 Analysis of Teacher and Student Interview Transcripts

For the student interview analysis, a framework, which was developed based on a combination of a grounded theory process (Glaser & Strauss, 1967) and considerations coming from the literature review on students' conceptions of theories and evidence, was used for the initial coding process (Appendix B2). This framework was developed and validated as part of the T2L study. The inter-rater reliability check between three researchers of a third of the total interviews (36/108) was more than 80%, which was deemed satisfactory (Miles & Huberman, 1994). The final framework of themes developed for coding the student interviews included the additional themes of: 'evidence supports theories', 'students' views on argumentation', 'students' views of science', 'notion of proof', 'notion of evidence' and 'seeing is believing'. To create a comparative account of each student's understanding of theories and evidence from the first and second interviews, the themes identified were utilised to create a detail description for each student, one of which can be found in Appendix B3.

The coding of the four teacher interviews was addressed separately for each teacher. The interviews of the teacher for Case Study 1 were coded and analysed after the analysis of his lessons and the same process took place for the teacher of Case Study 2. The coding process was not based on a framework, although the main themes identified were then structured around the three main areas that the interview schedule addressed, as mentioned in Section 5.5.3.1.

5.7 Issues of Validity and Reliability in Qualitative Research

Issues of validity and reliability of the findings were approached from a qualitative standpoint. Within qualitative research, validity 'has to do with description and explanation and whether or not the explanation fits the description' (Janesick, 2003, p.69) rather than as the term is used for statistical analyses. Therefore, the procedures of coding and analysis presented in Figure 5.3 were used in order to validate the accuracy of the findings from this study (Creswell, 2009). What is more, the validity of the findings can be established through a process of triangulation. Contrasting data from different sources based on a process of triangulation is utilised as a process of increasing the validity or credibility of the findings and explore any anomalous findings in qualitative studies (Creswell, 2009; Stake, 2003). For instance, within this study, triangulation of data can be performed based on the data collected from the student observations and the student interviews, to determine the extent to which students can use evidence in support of their views in different contexts. Another technique mentioned by Creswell (2009) that can add to the validity of the findings is to provide rich descriptions of the results, for example, through transcript extracts, as to allow the reader an insight to the data collected.

Reliability in qualitative research 'indicates that the research's approach is consistent across different researchers and different projects' (Creswell, 2009, p.190). A way to ensure the reliability of the findings is by employing other researchers to perform an inter-rater check of the coding process, as was described in Sections 5.6.1 and 5.6.2. Other strategies for ensuring reliability within a qualitative research project is to check transcripts for accuracy and mistakes, and, maintain definitions of codes updated so that there are not differences that affect the results of the coding process, two procedures that were followed with this study.

5.8 Ethical Considerations

Ethical concerns while doing qualitative research should be addressed adequately for maintaining the quality of the conclusions drawn from the various sources of data. Informed consent, privacy and identity protection, anonymity and confidentiality of information, as well as assuring that the participants will not be harmed in any way must be thoughtfully and deliberately planned (Burgess, 1989; Creswell, 2009; Fontana & Frey, 2005). For this reason, this study obtained ethical approval by the Ethics Committee of King's College London before it commenced and it conformed to all the ethical parameters set out by this committee. Teachers were provided with all the appropriate information as to allow for informed consent for participation. The participating students had already given consent to be observed and filmed through the T2L study. However, the students that comprised the group that was observed during the two case studies were further informed about the study by their teacher and were asked to give consent to be interviewed. Information and consent forms for the students' parents or guardians were also produced and provided to the participants. Appendix F includes all the consent forms provided.

Protection of identity was ensured in this thesis by anonymity of the participants. The two teachers that comprise the two case studies of this study were given pseudonyms that matched their gender. Student names were removed by all transcript extracts and numbers have been used instead to indicate when students are talking (S1, S2, S3 etc). Numbers where preferred over individual pseudonyms due to the large number of students in each classroom. In the same way, the four students, whose views of theories and evidence were investigated, were not named in the study. Finally, the video-recordings of the observations were not to be viewed by others than the members of the T2L project, which most teachers were familiar with. Moreover, confidentiality of the information collected was ensured through storing data on password-protected computers and external hard-drives, so that access was restricted to the researcher.

Ethical issues taken into account during the data collection process included the researcher-participant relationship (Merriam, 1998). The way that teachers and students perceived the power relation between the researcher and themselves, was also considered (Benton & Craib, 2001). It was essential that the participants did not feel threatened by any differences between the researcher and the participants, especially for the students, at any point of the two case studies. To ensure that the researcher-participant relationship was not guided by any power relations, the researcher attempted to influence the teaching context as little as possible. The teacher was asked about the lesson s/he would be teaching but no critical comments or suggestions that could be perceived in a negative way were made, to ensure that the teachers felt confident about their lessons. The discussions that usually took place after each lesson, were evaluative but with emphasis placed on what the teachers thought about the lesson and their impressions of how the students' worked during each lesson. The interaction between the students and the researcher was also minimal, as to not interfere with the students' normal behaviour during the lessons observed. The students that were interviewed, were given further information about the interviews from their teacher and the researcher, who was open to any queries or questions they had and willing to make the interview experience as comfortable for the students as possible.

Finally, during the analysis and writing-up stage of the case studies the researcher has the ethical responsibility to present the data collected in a truthful way without omitting any evidence that are contrary to any conclusions that s/he wishes to draw from the data (Merriam, 1998). Another issue to consider, particularly important for case study research, was the preserved anonymity of each case study during presentation and dissemination of results since the unique character and detailed accounts provided for a case study might reveal their identity. For that reason, information such as the name and location of the schools was not provided at conference presentations.

CHAPTER 6

CASE STUDY 1

JAMES AND HIS YEAR 9 CLASS ENGAGING IN EPISTEMIC TALK

6.1 INTRODUCTION

This chapter will examine the discursive actions of the first of the two science teachers participating in this study. The description and analysis of the argumentation and non-argumentation lessons of the first teacher is undertaken in order to provide answers to the first and second research questions. The following sections include a description of the teacher observed, the school and the students. Moreover, based on the two interviews conducted with the teacher, the teacher's views of science, argumentation and, teaching and learning science are provided. Then, a description and discussion of the epistemic features of classroom talk found in argumentation and non-argumentation instruction is presented, which includes an exploration of epistemic features within group-work and whole-class discussions. The examination of argumentation and non-argumentation lessons aims to answer RQ1 and identify forms of epistemic discourse within the two types of science teaching. Then, this chapter will present a comparison of the two ways of teaching science. This comparison is an attempt to determine whether the particular teacher has been using epistemic features of classroom talk related to argumentation on a more regular basis at the end of the project than at the beginning of the data collection process, so as to provide an answer to RQ2 of this thesis.

6.2 James and His Year 9 Class

James became a science teacher in 1990, a few years after obtaining a bachelor's degree in physiology. He had being teaching at the same secondary school for ten years. He held an Advanced Skills Teacher (AST)[3] position and was also responsible for the sixth form Biology courses as the Head of Biology. In his mid-forties, James was one of the senior members of the science department. The school was a mixed-comprehensive secondary school located in a quiet, residential area in the north-west of greater London. The science department of the school was involved in a previous research project focusing on developing argumentation practices, although James was not directly involved in that project (personal communication). James' involvement in the T2L project begun in the previous school year where he had the opportunity to teach argumentation to the group of students observed for this study and to other Year groups. The two lead teachers of his school along with James and another teacher had formed a group of four teachers that had taken the responsibility within their department of promoting and implementing the principles of argumentation and dialogic teaching in line with the T2L project's suggestions. In fact, he had taken part in one of the workshops organised as part of the professional development activities of the T2L project as the two lead teachers could not attend. In this respect, James had shown an active interest in utilising argumentation in his lessons and was willing to participate in the current study when contacted for that purpose in July 2009.

The class observed was a Year 9 (13-14 years old), mixed-ability group of 27 students (11 girls, 16 boys) mainly from an Asian/Indian ethnic background. The year that the lesson observations took place was the second year James was involved in teaching the particular group of students. He was one of their science teachers in Year 8 and then continued teaching them in Year 9, once a week. The particular Year 9 class was also taught science by another science teacher, twice a week. The lesson observations of James and his class took place during the 2009-2010 school year, starting in mid-September 2009 and ending at the beginning of July 2010.

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[3] ASTs train and support other teachers, and share with them their practice. They are usually required to spend 80% of their teaching time in their own schools and 20% teaching or working with teachers in other schools (http://www.education.gov.uk/schools/careers/traininganddevelopment/ast/a0013973/advanced-skills-teachers-asts)

Table 6.3: A summary of James' 13 lessons

	Argumentation	Non-argumentation	Epistemic operations
L1 17/09/09		**How do we know smoking is bad for you?** Students were given data in the form of a graph that represented a person's amount of nicotine levels in their blood throughout a day and were asked to interpret it. They were also shown what the ingredients of a cigarette are when it is lit by a whole-class presentation of a cigarette burning.	- Description - Explanation - Argument - Provides evidence - Procedural talk (during the demonstration)
L2 1/10/09		**Forces** Students explored the relationship of pressure and weight when standing on a surface. They were given scales and graph paper and asked to calculate the ratio between pressure and force acting on a surface. At the end, everyday applications such as the shape of a knife were discussed.	- Provides evidence - Definition - Explanation - Justification
L3 15/10/09	**Forces** Students had to choose among a series of statements to describe the fall of an object on a flow chart. They had to provide justifications during their discussions for each choice they made (IDEAS, Osborne et al., 2004b).		- Explanation - Justification - Argument - Evaluation - Counter-Argument - Compare & Contrast
L4 5/11/09	**Forces** Students were given a number of statements, which described what happens to a golf ball when struck. Students had to make a judgement on whether each statement was true/false/don't know and provide reasons for their decision (IDEAS, Osborne et al., 2004b).		- Description - Argument - Justification - Evaluation - Counter-Argument

	Argumentation	Non-argumentation	Epistemic operations
L5 10/12/09	**Photosynthesis** Students were given a graph of two gases and were asked to decide which was CO_2 and which O_2 justifying their decision with evidence from the graph. Then, they were asked to 'tell the story' of several points on the graph.		- Provides Evidence - Justification - Argument - Evaluation
L6 14/01/10	**Are pesticides a problem?** Student pairs were given different roles (farmers, organic farmers, consumers) and were asked to construct an argument to decide whether pesticides are a problem or not. They were then put into groups of 4-6 and were asked to consider which of the evidence provided to them could be used to counter-argue the positions of the other groups.		-Provides Evidence - Argument - Justification - Counter-Argument
L7 4/02/10		**Chemical patterns of carbonates** This was a practical lesson. Students were given three different carbonate solutions and were asked to determine what patterns appear in the chemical reactions of those carbonates. The lesson ended with a modelling activity of the reactants and the products of the chemical reaction.	- Description - Provides Evidence - Argument - Modelling - Procedural talk
L8 4/03/10		**Reactive metals** This was a practical lesson where students were given three different metals and asked to answer the question 'Which metal is the most reactive'. To do that they had to record data from the chemical reaction between the three metals and hydrochloric acid and produce a graph in support of their answer.	- Description - Provides Evidence - Justification - Argument - Compare & Contrast - Procedural talk

	Argumentation	Non-argumentation	Epistemic operations
L9 12/03/10		**Electricity/Patterns in Data** Students were given a diagram of a circuit with a voltmeter and an ammeter and were asked to build the circuit. Then, they were asked to determine whether any patterns existed between voltage and current using that circuit. To do that, students had to collect data and plot the appropriate graph.	- Definition - Description - Provides evidence - Compare & Contrast - Procedural talk (practical lesson)
L10 6/05/10	**Gravity on other planets** Students were shown a video of a space shuttle as it launched into space and were then asked to 'tell the story' of the astronaut's weight as s/he travels to the moon. Students had to construct arguments using evidence based on the weight, mass and gravity of the astronaut at each point of the journey.		- Provides information/ evidence - Description - Definition - Explanation - Argument - Compare & Contrast
L11 13/05/10		**Weight/Forces** This was a follow-up from Lesson 10. Students were given the weight and mass of an alien on different planets and asked to draw a force diagram of her standing still on Earth and the other three planets. Students were also given a sheet with criteria for their diagrams and prompts for explaining why the weight is different in each place.	- Description - Explanation - Argument - Justification - Compare & Contrast
L12 24/07/10		**Carbon Dioxide/acidity of solutions** This was a practical lesson. The lesson begun with brainstorming on CO2-why is it important; how it gets in the air. Then, students were given four solutions and were asked to classify them in order of acidity using a thermometer, universal indicator and marble chalk.	- Explanation - Description - Justification - Classification - Evaluation - Compare & Contrast - Procedural talk

	Argumentation	Non-argumentation	Epistemic operations
L13 01/07/10	**Air quality** Students were presented with evidence regarding a plant. They were then asked to draw a graph and use that to explain how air quality influences the presence or absence of lichens from the city centre.		- Provides Evidence - Explanation - Argument - Justification

Lessons were observed on the same day and time of the week – every Thursday, 13.35-14.25. Arrangements were made as to allow a lesson observation approximately once every two weeks. A total of 13 lessons were video-recorded including 7 ordinary lessons, three of which were practical lessons, and 6 argumentation lessons. For each observation, the teacher was asked to identify whether he considered or had planned the lesson as an argumentation lesson or not, in order to characterise the lesson as 'argumentation' or 'ordinary/non-argumentation'. Only Lesson 1 could fall within both categories since the teacher intended to plan an argumentation activity for that lesson but due to time constraints he was not able to (field notes, 17/09/2010) implement this activity. Table 6.3 presents a short summary and dates for each of the 13 lessons observed. Using the initial observations of the lessons, the planning information and resources provided by James[4], specific epistemic operations and types of talk that each lesson could afford was considered. These epistemic operations are presented in the fourth column of Table 6.3 and are used as an indication of the opportunities for epistemic talk that each lesson, could afford. Appendix G provides a detailed description of the 13 lessons and, a consideration of the differences identified between the affordances for epistemic talk and the actual epistemic talk found after the analysis of the transcripts. James was also interviewed twice through the school year. The first interview took place in January 2010 and the second interview in July 2010. The results of the interviews are presented in the next section.

[4] James did not provide lesson plans for all observations as this was not a requirement. For most lessons, information about the lessons was provided via email communication or in discussions about the lesson before the observation took place. All resources used in the 13 lessons observed were collected and included in Appendix G.

6.3 James' views on Nature of Science, Argumentation and the Teaching and Learning of Science

6.3.1 James' Views of the NOS and the Teaching of NOS Aspects

Through the two interviews, it was established that James had a good understanding of the explanatory purpose of science, he was aware of the creative and imaginative aspect of scientific processes and moreover, he had a sophisticated understanding of the nature and role of scientific theories and evidence, as shown below.

> 'People talk about creative subjects and they imagine that science isn't very creative but actually it is. And that's I suppose, countering theories, coming up with ideas to explain a phenomenon is quite a, it's a very creative process; especially when you have to deal with very abstract ideas…to visualise things in your head'
>
> (J1)[5]

Moreover, in both interviews, James drew from his own experiences as a student. He compared the way science was taught and presented at school when he was a student, which presented science as a body of factual information to be passed on to students, without any consideration of the processes that had led to the creation or establishment of that knowledge. James also mentioned uncertainty and the notion of 'facts' as other NOS aspects that could be presented to students within a science lesson. In particular, he commented that:

> 'this whole notion of fact, what's a fact; something you can prove happened rather than, […] in the past, science seemed like, for a lot of people including me I suppose, a series of diagrams and pathways and equations that had to be learned and sort of following some sort of logical sequence and they're related to each other in a logical way and were concrete and were written down and were, facts. Whereas […] the idea that all our knowledge and understanding is built on evidence and experimental data and observations and the whole notion of creativity and people having to come up with, having to create hypotheses to explain phenomena an test them, all of those things make it a bit more interesting'
>
> (J2)

[5] J1 and J2 indicate that the source of the extract is James's first or second interview respectively.

In fact, James also described NOS-based lessons he developed and taught at the beginning of each school year. The first lesson – called the 'jelly lesson' – was developed into an argumentation lesson by another teacher as part of the T2L project.

> 'Kids are presented with a phenomenon and have to come up with a variety of possible reasons that explain the phenomenon, and then we, by question and answer they come up with evidence and essentially what happens is they end up crossing out all those possible ideas based on the evidence that arises from their questioning and they kinda end up with no ideas left at all, in which case we can talk about you know what creative process you have to come up with new ideas; and we also talk about plausibility and what, as we cross ideas off what we are left with are the, those ideas that are still plausible based on the evidence. And sometimes you end up with one idea that is the most plausible sometimes you end up with nothing. And you've got to come up with something new, fresh'
>
> (J1)

In the above description, James was able to reflect on different aspects of the NOS that could be presented to students such as the empirical nature of science that is based on the use of evidence, creativity, and plausibility. However, it seemed that presenting students with the various facets of the nature of scientific knowledge and practices was not addressed as part of his everyday science teaching. Instead, aspects of the NOS were addressed in separate lessons by James. When asked whether he attempted to present students with the NOS aspects that he mentioned, he replied that he did teach some aspects of the NOS but there were not many lessons devoted to that. He also mentioned that at that point in time, students were presented with some of the historical context of the concepts taught, which was not included in science lessons before, as well as some argumentation lessons, mainly around ethical issues. Besides that, the science lessons he was required to teach as part of the National Curriculum were mostly content and examination-driven, something with which he was not satisfied (J1).

6.3.2 James' Beliefs About Teaching and Learning: Finding the Balance Between Challenge and Interest for Students

The two main issues that James raised when asked to consider how students learn were firstly, the need to provide students with opportunities to experience and relate to what they are learning. Secondly, he mentioned the need to find the appropriate balance between challenge and engagement in order to help students develop their understanding of the scientific concepts and processes taught.

> 'Kids need to be engaged […] Obviously, you are not necessarily going to engage everybody […] "are they challenged?" "Are kids getting stuck, are a broad range of abilities getting stuck in different places?" Cause that's a good thing. So, it's about engagement and about challenge. You can have things which are engaging but not challenging; that's not so good. You can have things that are challenging but not engaging-that's also not so good. But if you can have things that are, that engage them, that are challenging then that's magic, isn't it?'
>
> (J1)

Lessons that are sufficiently challenging and at the same time engaging can, according to James, be developed through presenting students with information in different ways, such as in the form of a puzzle and by using multimedia resources to maintain the students' interest levels. Additionally, the balance between engagement and intellectually challenging students could be achieved through argumentation. Particularly, he mentioned how as a science department they attempted to present students with alternative ideas and evidence and involve students in using those ideas to develop their understanding.

> 'we are also increasingly talking about trying to present, rather than telling kids this is the current idea because of this […], presenting them with a variety of bits of information, some of which are irrelevant, some of which support one idea some of which actually support a different idea or undermining the first idea and then asking them to sort those statements and come up with their own version of what makes sense and then we can talk about current thinking'
>
> (J1)

Even though James did not use the term 'argument' or 'argumentation' in the above extract to describe this approach of teaching science, activities such as considering various alternative ideas, allowing students to construct their understanding and then contrast it to 'current thinking' are activities that could be part of argumentation lessons. Moreover, the lesson that he provided as an example of this approach was an argumentation lesson observed a few days before the interview was conducted, which suggests that James had been influenced by the argumentation lessons he had taught until that point.

Finally, another element of James' approach to teaching and learning was the belief that students need to be given control over their learning. Therefore, part of his classroom culture was to encourage students to help each other when they 'got stuck' on a problem (J1). In fact, this was an initiative shared by the science department of the school. As James mentioned, they were trying to help students develop strategies for resolving a problem themselves or within their group instead of resorting to asking the teacher or going off-task.

> 'Rather than being so prescriptive with the practical work you say "right, this is the aim of what you're trying to achieve during this practical, here's the equipment, go and do it". And actually them thinking about what equipment do I need, what I'm trying to get out of this, what's the point. And they start asking themselves these questions, what's the point of me doing this, what I'm trying to achieve. So if they don't know how to set it up they've got to really think about what are they achieving, what outcome do they want from this practical before they even think about putting the apparatus together'
> (J1)

Giving students control and helping them being critical of their actions within a lesson was also part of the way that James described doing practical work in his classroom, as shown in the extract above. Based on the data, it could be supported that James held a view of learning that encouraged students' active participation in the learning process, with students' constructing their own knowledge. This view of learning is in line with social constructivist perspectives on learning (Driver et al., 1994), which support the use of dialogic argumentation as an approach to science learning and instruction.

6.3.3 James' Views of the Nature and Practice of Argumentation

The conception of argumentation that James held was that of argumentation as a way of thinking that students should be given the opportunity to develop during their school education. James defined argumentation as:

> 'having a viewpoint and being able to justify which might also mean being able to offer alternative viewpoints but being able to suggest why you haven't chosen, why you feel that the arguments, the evidence to support them is weak and you have evidence to support the argument you have chosen. So it's about, it's about having a viewpoint about something […] and…that is about weighing up the evidence isn't it? And making informed choices, which is what argumentation is about isn't it? Informed choices' (J1)

The same views about taking a standpoint and justifying that with evidence were given during his interview at the end of the project.

> '[Argumentation is] the idea of justifying your position, taking your position and justifying it based on evidence. But it's also about making decisions, like making a decision what to take off the trolley is taking a position and then if you're challenged you'll have to justify it so it's the same thing isn't it? Yeah, taking a position and justifying it really, but more than that I suppose it's about…how do we, the hard work is like this: *How do you know that? How do we know that?* (J2)

James acknowledged that one of the most difficult issues to deal within argumentation is for an individual to be able to present how s/he has come to know something, which requires the ability to provide evidentiary support in order to justify a position. James also recognised the importance of making decisions although he did not interpret that as the need to evaluate a situation but rather, he framed the act of decision-making as one having a viewpoint and using evidence to justify that viewpoint. When asked, James mentioned the notion of evidence as the aspect of argumentation he focused on the most, through asking students to interpret data and use them to justify their viewpoints. Moreover, James placed special emphasis on the ways in which argumentation can be beneficial for the development of students' critical thinking and reasoning abilities, which could help them in their everyday lives.

Apart from the advantages that James saw in using argumentation to teach science, he also identified a number of challenges, both for his students and himself. In particular, James' beliefs of the need for science teaching to be both engaging and challenging for students to learn, was an issue to consider when teaching argumentation since students often found the tasks of providing and justifying their viewpoints much more challenging than simply copying out from the board or reading out of a textbook. For example, in the first argumentation lesson he was observed teaching (Lesson 3, Forces) he mentioned that students had difficulty maintaining their focus on task. According to James, this difficulty was due to the level of challenge the activity held, which resulted into students going off task and him having to end the group-work activity. Instead of group-work, he ran a whole-class discussion of each of the statements students had to evaluate decreasing in this way the level of challenge put on the students, since he was controlling the discussion and guiding students through his questioning.

Another challenge was managing behaviour and sustaining student engagement during groupwork. Finally, finding the appropriate resources for argumentation lessons one of the main difficulties that James had when teaching argumentation, especially since he found it easier to adapt an argumentation resource to his students' needs rather than creating something on his own. As he mentioned:

> 'if you've got some resource that you can build your argumentation lesson around, then the argumentation lesson itself I don't find it more challenging. Some teachers say […] their perception is [argumentation lessons are] more challenging cause the teachers got to [inaudible] not knowing all the answers and being just, a sounding board for the kids. I've always kind of worked like that in a way so I haven't found that particularly difficult but you need to have a nice resource to build the lesson around it because...that often means you've got to create something because there aren't that many resources that support that kind of approach. But in terms of the lesson what's different [is that] students are more in the driving seat'
>
> (J1)

James seemed to be comfortable with the idea that a teacher does not need to know all the answers during a science lesson, and what is more, he seemed to believe that his own teaching practices were aligned with teaching science using argumentation. As he said in the extract above, being a 'sounding board for the kids' was an approach he took during his lessons, as well as questioning, which he considered as one of his positive skills as a science teacher (J1). Hence, his stance towards teaching argumentation and his perceived skills in doing so, were positive.

To sum up, James held views of the NOS consistent with contemporary perspectives of the philosophy of science. In particular, he acknowledged and considered the importance of creativity and imagination for the creation of knowledge. He also emphasised the empirical nature of science and the importance that evidence has on the creation and establishment of scientific knowledge and finally, he was able to reflect on the tentativeness of scientific knowledge and how that could be presented to students. What is more, his views on teaching and learning seemed to be aligned with perspectives that were in support of using argumentation to teach science since he stressed the importance of challenging students during the learning process, allowing them to find their own ways of getting 'unstuck' (J1; personal communication) and give students control over their own learning process. These views of learning although not specific to the practice of argumentation, provide opportunities for the students' engagement in discursive interactions and active participation in the learning process, and thus are conducive to the use of argumentation as a teaching approach. James also seemed to be concerned with the ability levels of his students, which could restrict him from pushing further and challenging his students during argumentation lessons. Finally, his views of argumentation were based on the use of evidence as a means of providing justification for a claim. The ways James translated these views into his teaching practices and whether they have influenced his ability to use epistemic discourse when teaching argumentation and non-argumentation lessons are explored in the following sections.

6.4 Epistemic Features of James' Classroom Talk During Argumentation Instruction

The nature of epistemic discourse during the 6 argumentation lessons James taught was framed based on the notion of 'epistemic operations' presented and discussed in Chapter 3. As a result of the analysis, two main categories were created in which the discursive actions or epistemic operations of the teacher were organised (Appendix D1). Firstly, based on the discursive actions the teacher *performed* where he was attempting to explain, define or describe an event and secondly, based on discursive actions that aimed to *prompt* or engage students in the learning process. Moreover, a subcategory that represented the organisational format of the activities whilst the teacher was talking was created. The two organisational formats of James' classroom activities where 'whole-class' used when the teacher was addressing all students and 'group-work' during which the teacher was talking with or to students, as they were engaging in group activities. The results of the analysis for James' argumentation lessons are presented in Tables 6.4 and 6.5. The percentages included in the two tables are based on the total number of epistemic operations identified in the teacher's classroom talk (which includes both the operations performed and prompted by the teacher as to provide a comprehensive picture of the teacher's classroom talk during those lessons). The results presented in Tables 6.4 and 6.5 provide a basis for the discussion of the epistemic features that were found in James' classroom talk, which is presented next.

Table 6.4: Epistemic operations performed by James during argumentation instruction

	Coding References[6] (%)	Group-work	Whole-class
Provides evidence	74 (8.7)	38	36
Evaluation	62 (7.3)	33	29
Justification	58 (6.8)	26	32
Description	49 (5.8)	14	35
Generalisation	38 (4.5)	15	23
Compare and contrast	37 (4.3)	24	13
Exemplification	37 (4.3)	13	24
Definition	37 (4.3)	15	22
Counter-argument	32 (3.8)	18	14
Modelling	27 (3.2)	4	23
Explanation	25 (2.9)	9	16
Argument	12 (1.4)	5	7
Analogies & Metaphors	10 (1.2)	2	8
Prediction	6 (0.7)	2	4

To facilitate the discussion James' epistemic operations were organised based on the three main epistemic processes that Kelly (2008) utilises to describe and define the epistemic practices of science; the construction, justification and evaluation of knowledge claims, and on which the discussion on epistemic practices in Chapter 3 is based.

Table 6.5: Epistemic operations prompted by James during argumentation instruction

	Coding References (%)	Group-work	Whole-class
Prompts for Evidence	80 (9.4)	55	25
Prompts for Justification	64 (7.5)	33	31
Prompts for Argument	49 (5.8)	29	20
Prompts for Evaluation	52 (6.1)	31	21
Prompts for Prediction	32 (3.8)	16	16
Prompts for Counter-Argument	31 (3.6)	18	13
Prompts for Description	24 (2.8)	15	9
Prompts for Comparison	11 (1.3)	8	3
Prompts for Definition	2 (0.2)	2	0

[6] 'Coding references' indicate the number of times each code has being applied

6.4.1 Constructing Knowledge Claims: 'Providing Evidence', 'Description', 'Argument', and 'Explanation'

6.4.1.1 Providing and Prompting for Evidence

An important aspect of the discursive actions of James' classroom talk during argumentation lessons was providing evidence to the students. 'Providing evidence' was considered as any instance where the teacher was giving students information or data that they could then utilise as evidence in their investigations, such as 'smoke actually also contains particles of soot which are little bits of carbon, solid. Little bits of solid material' (L13). As evident in Tables 6.4 and 6.5, the epistemic operations of 'Provides Evidence' and 'Prompts for Evidence'[7] are the two most common discursive actions used in James' classroom talk. This would suggest that a considerable amount of the on-task talking that took place during James' argumentation lessons focused on providing students with the necessary information that would help them construct their knowledge of scientific concepts and use this knowledge for their investigations.

By providing information and evidence, the teacher was setting up the stage for the students to be able to argue. As James commented in his interviews (Section 6.3), evidence and the ways in which students use them to construct arguments and make decisions was an aspect he emphasised in his teaching. During the argumentation lessons observed, James often mentioned the importance of using evidence and discussed the role of evidence in scientific investigations with students. For example in Lesson 13, he commented:

> 'In order to make a judgement about how good or bad the air quality is you are going to have to use evidence. Cause you have to use evidence to make judgements about everything, don't you?'
>
> (L13)

[7] In the two thematic categories of 'Provides Evidence' and 'Promtps for Evidence' the information that the teacher provided or prompted students to provide, was not always used as evidence in the follow-up discussions by students. However, the term 'evidence' is used to avoid the use of the double term 'evidence/information' throughout the thesis.

'Prompts for evidence' usually aimed at retrieving information that was previously taught or establishing the students' current knowledge base, as in the following extract from Lesson 3.

> **32** So, there's a force going down, there's a force going up, and they are the same size. What's the force going down?
> **33** S: Gravity.
>
> (L3)

During this lesson James asked students to draw the forces acting on an object and was prompting students for information to ensure that they knew which were the forces involved, something they were taught in their previous science lessons.

6.4.1.2 'Description', 'Prompts for Description' and 'Generalisation'

Supplying students with evidence was achieved not only through providing information or evidence, but also through the use of epistemic operations such as 'Description', 'Definition' and 'Generalisation'. For instance, in the following example of a 'Description', James was describing the parts of a space shuttle. In doing so he provided evidence students could use in the task they would be subsequently involved in, which was to describe what happens to the mass, weight and gravity acting on an astronaut as s/he makes the journey from the Earth to the Moon.

> 'at the top is the command module with the three astronauts sitting in it, underneath that you've got the rest of the command module; inside here is the part that will actually land on the moon and then you've got a third stage, a second stage and a first stage of the rocket with the engines down here. The only bit that comes back to earth is that bit on the top; that little bit there. And the only bit that goes to the moon is that little bit in there. And that structure weights three thousand tones'
>
> (L10)

'Description' was a prominent feature in the discursive actions of this teacher, which took place mostly during whole-class interaction (71%) of the argumentation lessons, and usually served the purpose of setting up the context for the lesson or the activity to follow. It is worth noting that although 'Description' was one of the actions that the teacher was using often when talking to the students, it was not a discursive action that he aimed at engaging students in, as shown from his use of 'Prompts for Description' in Table 6.5 (24 coding references in 5 lessons, Appendix H). For the most part, prompting students to provide a description was used by the teacher as a starting point for the students to discuss in order to proceed to the more challenging parts of the activities. This was the case in the following excerpt. During a group work activity James was rotating around the four main groups in the room and was using the same prompt for the students to attempt to describe the lines in the graph provided (Appendix G) before they could move on to constructing their own explanations.

> *'First thing you need's a very precise description of each of those lines*[8] and then a careful explanation in terms of photosynthesis, what you know about photosynthesis' (L3)

'Generalisation' was another epistemic operation that James was engaging in when talking to the students, again especially during whole class interactions and usually accompanied by the word 'so'. An example was the following example during Lesson 6. At the end of this lesson, James asked each group to present their argument and then invited other students to provide counter-arguments in a whole-class discussion. In this extract, a student attempted to rebut the evidence statement 'some scientists think that there is no safe level for pesticides', and James asked him to repeat his viewpoint. In lines 375 and 377, James provided generalisations of what the student had said in order to share that view with all students in the classroom, and establish the difference of opinions.

373 OK what was the first point you made? Something else you said?
374 S: They said *some* scientists; that means all the others don't.
375 Right so they used the word *some,* so, so some scientists believe something that means lots of other scientists don't. Is there anything else you might like to add? Did you use the word 'may' somewhere?
376 S: Yeah they said pesticides *may* cause brain damage.
377 Right so that doesn't mean that they do; there's some doubt there.

The use of this epistemic operation is similar to what O'Connor, Michaels and Resnick (2010) describe as 're-voicing'. Through their work with teachers these authors have found that when teachers talk they often re-state what the students have said. This 'talk

---

[8] Text in italics shows the prompt to describe an event

move' is considered by O'Connor et al. (2010) as a way to advance students' accountability to the community in which they are working, by sharing the knowledge with all members of the classroom and inviting other students to express their views on what has been said. In the case of James, 'Generalisation' was used as a way to establish some common ground for the students to continue discussing, as in the example above, where he made a generalisation in order to summarise what a group of students had being discussing.

6.4.1.4 'Argument' and 'Prompts for Argument'

'Argument' as an epistemic feature of the argumentation lessons observed served the purpose of externalising a position and supporting it with evidence, as this was modelled to the teachers of the T2L project based on Toulmin's argument framework (Figure 2.1). As the 6 lessons under discussion had all been characterised as 'argument-based' by the teacher himself, it was expected that a considerable amount of the talk that would take place in these 6 lessons would be forming and modelling arguments by the teacher as well as prompts for students to construct their own arguments. 'Argument' was present in five of the six argumentation lessons taught (Appendix H). One of the purposes James had for forming an argument was to model the process of argumentation for the students and explicate the components of a good or bad argument (opinion/view, evidence, justification, counter-argument), usually at the beginning and end of an argumentation lesson. Figure 6.5 presents the way James had chosen to model argument for his students in Lesson 5.

Figure 6.5: A generic model of argument by James in Lesson 5

ARGUMENT IN SCIENCE: Use evidence to justify your thinking

Looking at data

DESCRIBE
EXPLAIN
JUSTIFY
ARGUE

The teacher provided students with the above model of argument on the board, which remained there throughout the lesson. Once the lesson begun, James explained to the students what the aim of the day's lesson was, as shown below.

27 OK, this lesson is about argument, OK? "Yes, it is/No it isn't; Yes, it is/No it isn't". That's not argument. OK? When we talk about argument, what we mean...
28 S: Explanation.
29 Yeah*. Justifying your thinking, essentially that's what argument is. Justifying your position.* OK? We're going to look at some data. It relates to photosynthesis which is why you started off thinking about those four statements […] So, now you are going to have to play with those ideas, you're going to have to apply them, OK? *You are going to have to make some decisions but you're going to have to justify those decisions. That's what argument is. OK?* ***So you are going to be describing things, explaining them and justifying them****; in other words you are going to be arguing.*
(L5)

In the extract above, James made explicit one of the main components of argument –the use of data as evidence – and the function of evidence within an argument so as to justify a position. However, he also equated argument to justification, two constructs of different epistemic function. Justification is only part of the process of argumentation and of the final product of it, which is an argument. Even though justification is an integral aspect of the process of argumentation, it is not the only aspect that characterises argument. Rather, it is the first step in thinking about the construction of an argument. One first needs to create a claim and provide evidentiary support for it, and in this way, justify it, but this justification process also entails an internal consideration of possible counter-claims that need to be covered for the product of this argumentation process to be epistemically sound. Thus, justifying a position is not the same as constructing an argument, which requires not only the support of a claim through evidence but also the consideration of alternatives which need to be rebutted providing counter-evidence. The implicit consideration of alternative view-points or counterarguments is particularly important when attempting to form an argument based on Toulmin's argument pattern (Figure 2.1), since such an argument requires not only the inclusion of claims and evidence as warrants but also rebuttals and qualifiers as to increase the strength of the argument put forward.

James' move to present argument and justification as synonymous, could mirror his own views of argumentation as well as being a way of emphasising the importance of justification as part of the process of arguing. In any case, by framing argument in this manner, James was explicitly making the connection between the action of describing, explaining and justifying statements, which he seemed to consider as an overall attempt to argue (as shown in the bold text of utterance 29, p.133). In this way, he presented to the students the epistemic operations they should be undertaking during their group-work activity. Moreover, these actions were presented by James in a developmental sequence of 'epistemic load', moving from actions of lower epistemic load, such as 'Description', to actions of higher epistemic load, such as 'Argument' and 'Explanation'. During this lesson, students were given a graph with two lines (representing the levels of CO_2 and O_2 in the atmosphere over a period of 24 hours, Appendix H) and were asked to identify the two lines. In order to do so, James instructed them to first attempt to describe the two lines on the graph given in order to explain what is happening at each point of time throughout the 24-hour cycle. In this way, students would have to use what they already knew about photosynthesis as evidence to justify their selection of a line from the graph as CO_2 or O_2.

A different way of modelling argument to the students was providing them with an 'exemplar argument' during which James reflected on the function and usefulness of each statement in the process of constructing an argument. An example of this process took place during the last argumentation lesson James taught (Lesson 13). During a whole-class discussion at the start of the lesson, he provided students with examples of both arguments and counter-arguments and discussed with them each of the elements that an argument needs to include. Text in italics shows the meta-language James used to explain to students the steps he used to construct an argument first, and a counter-argument a while later.

11 In order to make a judgement about how good or bad the air quality is you are going to have to use evidence. Cause you have to use evidence to make judgements about everything, don't you? For instance, someone might say to you that England are a rubbish football team.

12 Students: They are; it's true.

15 But, but unless they offer you some justification that is not an argument […] If I was to say to you that England are a rubbish football team because Germany beat them 4-1 and should've beaten them 9-1, ok, 9-2 maybe, and every time the Germans came at the English great holes appeared in the English defence through which the Germans were able to run and score, then, *I've presented you with an argument because I've given you some justification for suggesting that England are a rubbish football team. If I just said to you England are a rubbish football team that is not an argument. It's just a statement. But if I back it up with some evidence*...here's another example, ok. Frank Lampard scored a goal, the goal was disallowed by the referee; there's now a discussion going on about whether we should have goal-line technology.

16 S: Yes.

17 You can argue for or against goal-line technology. People who argue for goal-line technology say that it’s important that the right decision is made because these decisions are really important. In terms of economics, in terms of politics and in terms of the way our country feels about itself. They're big decisions; you’ve got to get them right. Goal line technology would eliminate mistakes like the ones we saw in the Germany game. However, people would argue that goal-line technology slows the game down. That you lose the flow that makes football so entertaining. Somebody else might argue that that's not the case because if you had a fourth official who was watching everything on video playback, they're connected to the referee by a wireless microphone and in seconds they could inform the referee of a problem and the problem could be resolved. *What I have just done is I just presented you with an argument. I've got a position-should we have goal-line technology, shouldn't have got goal-line technology- and I justified my position. OK? And in fact, we offered a counter-argument as well, didn’t we, to the goal-line technology? It stops the flow; actually it doesn't because bla, bla, bla.* OK? Argument. Now, when you make judgements about things scientifically you've got to use evidence to justify your argument so you in a moment will have a look at some evidence and you've got to come up with your own opinion about what it says about air quality’

(L13)

In this case James included not only the use of evidence as justification for support of an opinion but he also provided a description and example of a counter argument. Students need not only be able to argue in support of a viewpoint but need to also be in a position to refute alternative positions, always with the appropriate evidentiary support. This explanation of argument compared to the first one presented from Lesson 5 on page 133, shows that James was at that point starting to consider other aspects of the process of argumentation with his students, such as counter-argument. This would suggest that his initial, and somewhat, simplistic representation of argumentation, was starting to become more complex in nature and include aspects of argument that were more cognitively challenging for the students, i.e. counter-argument. Nonetheless, the prevalence of justification over other facets of argumentation was still present in his descriptions and definitions of argument, as can be seen in the above extract from Lesson 13.

In contrast to the teacher's construction or presentation of arguments to the students, 'Prompts for Argument' was the third most frequent prompt the teacher was using to encourage students' talk in the classroom, after 'Prompts for Evidence' and 'Prompts for Justification' (Table 6.5). This action would suggest that the teacher was more concerned with enabling students to construct their own arguments rather than using arguments himself. This is consistent with his continuous attempts to provide students with evidence and justifications as to enable them to construct arguments, explanations and provide reasons in support of their arguments. However, the difference identified between the prompts for arguments and the teacher's own provision of arguments, raises concerns about how are students to learn how to construct arguments if their teachers are not themselves consistently using them as part of their classroom talk, since as mentioned in Chapter 2, research suggests that the students' talk is influenced by the way that teachers talk in the classroom (Webb et al., 2006; Gillies & Khan, 2009).

6.4.1.5 'Explanation'

Another epistemic operation found in James' classroom talk was 'Explanation', which was considered as every instance where the teacher made causal links between events of a phenomenon, as in the following example.

62 S: I don't understand why the rocket is so big if it only holds people at the top.

63 The amount of energy required to lift those three astronauts and that little bit of aluminum plus the little bit in there that's actually going to the moon, the amount of energy required to lift that out of our atmosphere, out of our gravitational field and then send it a quarter of a million miles to the moon and then bring it back again, is phenomenal. And most of that rocket, in fact all of that rocket is liquid oxygen and kerosene. Liquid oxygen is like petrol, it's used in jets, it's jet fuel. So, most of that rocket is just fuel and oxygen. Oxygen enables the fuel to burn to release the energy to get it all the way and back**'**

(L10)

Overall, in the 6 argumentation lessons observed 25 instances had been found where the teacher was providing an explanation of a phenomenon. From those 25 instances, most came during whole-class interactions (64%) and in lessons where forces and the relationship between gravity, mass and weight was the topic of discussion. The function of explanation within these argumentation lessons was to establish students' prior knowledge and understanding of the phenomenon discussed as to be able to create an argument, and vice versa. That is, through prompting students to create arguments and use their prior knowledge on the issue discussed, students were guided towards the scientific explanations of concepts such as gravity. For instance, in Lesson 3, where students were asked to consider what happens to a box as it is let to drop from a height of 1000 meters, the teacher explained how gravity and the distance from the earth influence the forces acting on the object, while presenting students with a different idea or counter-argument.

349 Why do you think that gravity gets a lot bigger as the box gets closer to the earth?
350 S1, 2: Because we did the [experiment with the] pencil.
351 All right, because the pencil speeded up and seemed to move even faster when it closer to the earth. […]*I overheard somebody else telling me about space and about the fact that if you go into space you have no, there is no gravity so the idea that maybe the further away from the earth you get the less gravity there is in which case that person felt that, that 3B was the right answer for that reason.* Ok, did anyone pick 3A [gravity is roughly the same size throughout the fall]? OK. S3, why did you pick 3A?
352 S3: Because a thousand meters is not high up.
353 So are you happy with the idea that gravity changes as you move away from the earth, like these guys thought, but you don't think a thousand meters is very far away from the earth so you don't think it's going to change very much. So you've gone for [statement] 3A. OK, and where you the same?
354 S4: Yes.
355 OK. I'd go with them [S3 and S4]. So you are all right but they are more right than you are. It changes but it doesn't change very much over a thousand meters. If you think about it, if you went to the top of a sky scraper, if you go to Canary Warf or something…

(L3)

In utterance 351, James stated to the whole-class one of the arguments that students in groups were expressing (in italics). He then moved on to ask if any students thought statement 3A was correct, prompting them to provide an alternative argument to the one he stated (that the further you are from the earth, the less gravity there is). In encouraging students to consider statement 3A, which was the best out of the three (Appendix G) and provide him an argument for why 3A is the best, he was leading students towards the scientific explanation of the phenomenon they were discussing in the classroom. Moreover, James was presenting students with an alternative argument to the one they had constructed in order to help them develop an understanding of how gravity affects mass in space and within the earth's atmosphere. In cases such as the one above, the teacher was putting forward a scientific explanation as an argument, by providing alternative views, one of which was the correct scientific explanation that he wanted his students to understand.

Berland and Reiser (2009) suggest that 'explanations are developed through argumentation' (p.27) since the statement that will eventually consist of an explanation is put forward for revision, evaluation and questioning by other members of the community or group of students. Similarly, it could be claimed that within the science classroom, explanations are presented to students through the process of argumentation. For instance, the explanations that James provided his students with, were often put forward in a discussion as arguments for the students to consider, along with alternative arguments, which were usually the ones provided by students. In this way, James was contrasting the scientific explanation to other viewpoints or arguments that the students had, but at the same time, he avoided being authoritative and absolute only accepting to consider the scientific explanation. Thus, he was able to help students understand why the scientific explanation was better than opposing ones. In this sense, the use of the discursive action of 'Explanation' as part of an argumentation lesson would be to promote the content of the scientifically accepted explanation of a phenomenon as part of the process of arguing. Therefore, although an explanation for a phenomenon is considered established knowledge, the way in which an explanation will be negotiated during the lesson, makes argument-based instruction important. This importance is demonstrated through the opportunity that is given to the teacher during argument-based instruction to engage in a dialectic between 'construction and critique' (Ford, 2008a). The teacher can take the role of the 'constructor' of knowledge and negotiate with students the correct scientific meaning of ideas whilst at the same time he is evaluating the students' arguments and providing them with alternative ones as to establish the validity of the scientific explanation amongst the students.

To further explore the manner in which James utilised the evidence and information he provided to the students, an exploration of the epistemic operations of 'Justification' and

'Prompts for Justification' is provided in the next section. The process of justification is an essential component of epistemic operations discussed above such as 'Explanation', 'Argument' and, 'Prompts for Argument' and a necessary condition for the development of students' arguments based on reasoning and evidence.

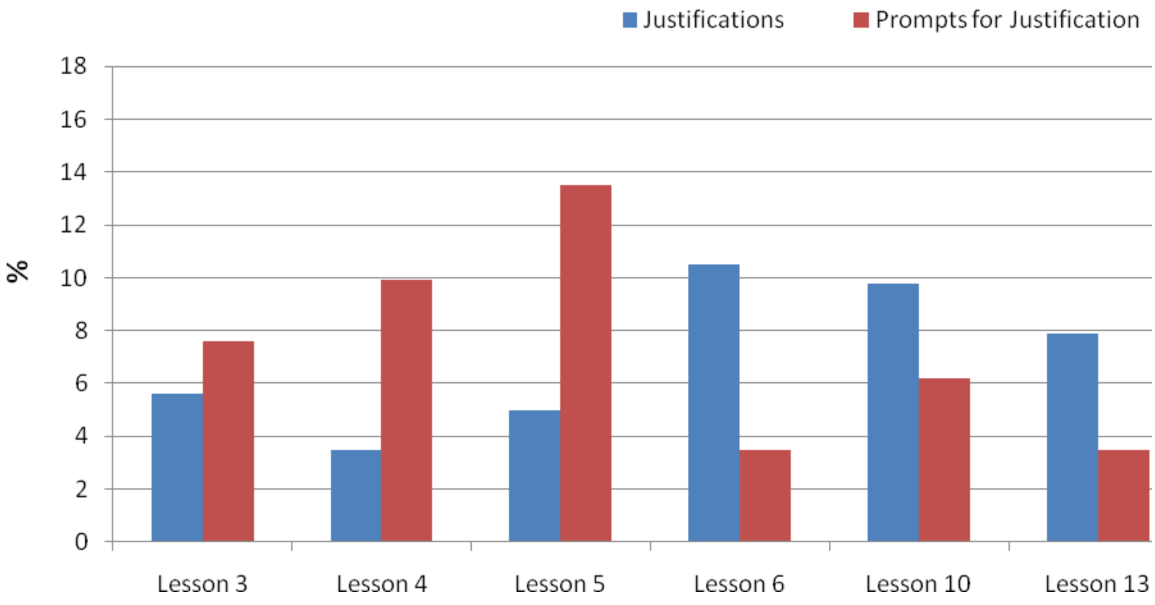
6.4.2 Justifying Knowledge Claims: Providing and Prompting for Justification

An aspect of James' argument-based instruction that mirrored his views on the importance of using evidence within a scientific investigation was his perception of justification, its role within argument, and within science. Within James' 6 argumentation lessons, justifications provided were found to have different functions. The first way they were used was epistemic, in the sense that they provided support for a claim or explanation provided by the teacher. As a consequence, 'Justification' could in some cases be part of explanations the teacher was providing, although, not all justifications provided could be considered as explanations, and vice versa. For instance, in the following example, an 'Explanation', the teacher also included a justification (indicated in italics).

> 'the idea is that respiration and photosynthesis are happening at this point, both happening, but the oxygen level is going up overall *because there's more oxygen being produced than is being taken in for respiration*'
>
> (L5)

The second way in which justification was utilised was in a procedural or reflective role where the teacher again used evidence but in order to support a statement of a reflective nature, such as 'don't just [go] through choosing and then think you're finished; cause you may be asked to tell us why you think that's the case' (L3) or of a procedural nature such as 'OK, I think you need to have a chat about it cause you're not a hundred percent sure of it' (L10). Figure 6.6 presents a summary of the justificatory comments identified in the argumentation lessons observed. These are presented as a percentage of the total number of epistemic operations identified in each lesson separately.

Figure 6.6: Justificatory talk in James' argumentation lessons



James' use of 'Prompts for Justification' was another way in which the importance of justification was demonstrated and promoted in the argumentation lessons observed. As shown in Table 6.5, 'Prompts for Justification' was the second most frequently used epistemic operation in which James attempted to engage his students. In addition, the proportion of its use was equally shared amongst whole-class and group-work, which suggests that 'Prompts for Justification' was a discursive practice utilised consistently during these lessons. James acknowledged the importance of the justificatory aspect of scientific practices and utilised it in both his own practices as a teacher but also as an epistemic action he encouraged his students to develop.

Furthermore, within his argumentation lessons, there were 60 instances where James used 'why' as a question or a prompt for students to consider, as shown in the following examples from Lesson 3.

169 S1: [] It's this one, steady speed.
170 That's interesting. OK. Remember you are going to have to justify this choice; *you are going to have to say why you've chosen...*
171 S1: Because if you let it in space, because it's higher everyone floats.
172 Oh, right.
173 S1: 'Cause there's no gravity up there, there's less gravity. (L3)

Epistemic enquiring through the use of questions such as ‘why’ and ‘how do you know’ is an important element of the practice of argumentation since often it is based on such questioning that the construction of an argument is initiated and developed. In this respect, prompting for justification serves a significant function within any epistemic practice. Additionally, justification and its role within science was one of the fundamental ways in which James conceptualised the notion of argumentation, as shown by his interviews both at the start and end of the study (Section 6.3).

6.4.3 EVALUATING KNOWLEDGE CLAIMS: ‘EVALUATION’ AND ‘COUNTER-ARGUMENT’

The evaluative processes of scientific practices were operationalised in James’ classroom talk in different ways. Firstly, through the presence of the epistemic operation of ‘Evaluation’ and secondly, through ‘Counter-Argument’.

6.4.3.1 ‘Evaluation’ and ‘Prompts for Evaluation’

As can be seen in Table 6.4, ‘Evaluation’ was another common feature present in the argumentation lessons observed. Yet, the quality of evaluative comments made by James varied. For instance, one of the forms that ‘Evaluation’ took was that of an IRE pattern. In fact, from the 62 instances that ‘Evaluation’ was found in argumentation lessons, 28 were classified as IRE (Appendix H). In these 28 instances, the evaluative comments provided by James were short and occurred during ‘question and answer’ sequences when talking with individuals or groups of students. This form of evaluative comments is not thought to serve an epistemic purpose beyond the verification provided by the teacher, as simply he was providing feedback to what the students were saying and did not encourage an active participation of the students in an evaluative process. An example of an IRE exchange between James and students is the following:

402 So is it true or false?
403 S: False.
404 False. So that statement is incorrect. Right. (L4)

In the example above, James checked what the students thought only, and he did not attempt to provide any further elaboration, beyond providing them with an evaluative comment. Besides evaluative comments based on IRE, James utilised another, more epistemic, way of providing evaluation to students' responses. This 'epistemic evaluation' was usually accompanied by epistemic operations such as 'Generalisation' or 'Explanation', as in the next extract from Lesson 10.

208 So what happens to your weight on the Moon?
209 S: Lighter.
210 Right. Which is why when you see the astronauts walking across the moon they sort of bounce cause their bodies are built for gravity on earth, so when you take a step, your muscles, you've learnt, your muscles have learnt subconsciously to do just enough work to put you on to the next step.

(L10)

In the example above, utterance 210 would be considered as IRE if James just replied with 'Right' to the student's response and moved on to another question. However, the fact that after agreeing with the student he then moved on to provide an 'Exemplification' and an 'Explanation' of the astronauts' movement on the Moon, based on the student's reply, made his comment to the student more epistemic to the simple reply of utterance 404 provided in the example from Lesson 4 above.

Another example of epistemic 'Evaluation' is provided in the following example where the teacher attempted to show the students how the overall force acting on a moving object does not remain in the same direction.

293 So if the ball goes like that, is the overall acting on the ball, the net force always in that direction?
294 S1: Yes.
295 S2: Yeah.
296 S1: [inaudible] it goes up and down.
297 OK. Right. Watch. I push the trolley yeah? The trolley moved that way. Was the overall force acting on the trolley always on that direction [direction of movement]?
298 S1: [yes]
299 *Was it?*

(L4)

In this extract, James provided an evaluative comment in utterance 297 by accepting the students' opinion and then demonstrating again to students what happens when he pushes a trolley. The second time the two students maintained the direction of the overall force did not change he questioned their answer (utterance 299) implicitly suggesting a counter-position to the one that the students proposed and then moved away leaving them to reconsider their answers. The combination of evaluation and the implicit suggestion of a counter-argument in line 299, was a practice found in James' discursive interactions with students. In this case, even though he did not directly propose a counter-position he did question the students' responses in a way that encouraged them to reflect on their position and reconsider their answers. This discursive action of suggesting alternative viewpoints is important for the establishment of a classroom culture that accepts and encourages students questioning each other's views, a practice that promotes an evaluativist position on the creation of knowledge (Kuhn, 1991; 2005).

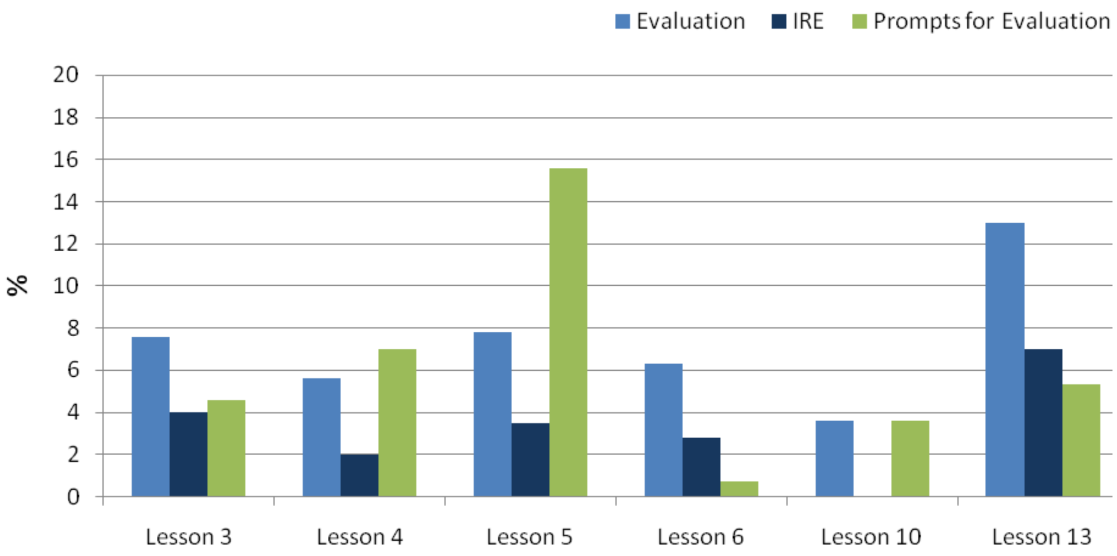
Moreover, during questioning sequences such as the one presented above from Lesson 4, it seems that even though James was guiding students towards the correct answer or explanation for the topic of discussion, he was nevertheless avoiding directly stating the right answer to the students. Instead, he attempted to elicit the responses he wished through further questioning and prompting students to consider alternative evidence and viewpoints. For instance, at the end of Lesson 5 James provided a final evaluative comment to the students telling them which was the right answer but he also reflected on that explicating that 'the important thing is your description, the numbers you picked and your explanation, the letters you picked to justify your choice' (L5, utterance 419). A similar example is the next, during which he was helping a pair of students develop their argument.

278 Did you ask me something?
279 S1: Yeah, will that be true?
280 Why do you think that's true?
281 S1: Cause the net force is in the same direction as the ball […]
282 *Is it?*
283 S1: I don't know.
284 S2: I said false.
285 So you don't agree. Why do you think it's not f, true?
286 S2: Because the overall force and that includes air resistance and all that, so when it's in the air, there is air resistance and air resistance isn't going to the way that the ball is moving.
287 Which way is air resistance going?
288 S2: The opposite direction.
289 Ok. So what's the overall force on the ball? So the ball is going to go like this yeah? OK? *The question is, is the overall force on the ball always in that direction? Always that way or not?* (L4)

In this case, James questioned the students' response again suggesting implicitly a different view, but he also took the discussion with the students a step further by prompting them to evaluate the situation and provide a counter-argument in utterance 289. The teacher's use of 'Counter-Argument' is discussed in the next section.

As in the case of 'Argument' and 'Prompts for Argument', the epistemic operation of 'Prompts for Evaluation' was a more explicit attempt on the part of the teacher to engage his students in the process of evaluation. Figure 6.7 presents a synopsis of the evaluative comments identified in James' classroom talk, including 'Evaluation'[9], IRE instances for each lesson and 'Prompts for Evaluation'.

Figure 6.7: The evaluative comments made by James in argumentation lessons



As can be seen in Figure 6.7, 'Prompts for Evaluation' were used especially in Lesson 5 and in Lesson 4, where students had to decide whether the statements provided to them were true or false and again justify their decisions.

> 'The rest if you're not actually involved in doing that, you are listening. You may be asked to repeat what somebody else just said, you may be asked what you think about it. *You may be asked to evaluate it; if you agree or not*'
>
> (L4)

[9] In Figure 6.7, 'Evaluation' includes both the instances of IRE and epistemic evaluation found in the teacher's talk.

'Prompts for Evaluation' is considered as more epistemic and challenging than 'Evaluation'. James utilised Evaluation in an IRE form approximately half the times he provided an evaluative comment in each of his lessons (Figure 6.7), providing feedback to students and moving on to other questions. What is more, his use of 'Prompts for Evaluation' was not as often as other epistemic operations, such as 'Prompts for Justification' and 'Prompts for Evidence' (Table 6.5). This would suggest that the evaluative practice of science is not a consistent part of James' teaching practices and talk.

6.4.3.2 'Counter-Argument' and 'Prompts for Counter-Argument'

Another aspect of the evaluative processes that took place in the lessons observed was the utilisation of 'Counter-Argument' as an evaluative mechanism. Teacher and students need to be able to evaluate a position before they can offer a counter-position and/or counter-evidence. In the argumentation lessons taught by James, 'Counter-argument' was present in his classroom talk (Table 6.4), especially in combination with evaluative comments, as shown in the extract from Lesson 4 on pages 143. Yet, he did not make an explicit effort to prompt students for counter-arguments in all of the lessons observed. Specifically, 'Prompts for Counter-Argument' was present in only four of the six argumentation lessons observed, with the vast majority of instances (26/31, Appendix H) being in Lesson 6, where the specific focus was on identifying counter-evidence and constructing counter-arguments.

During the introduction of Lesson 4 he suggested the creation of counter-arguments by the students by suggesting that:

> 'You have to read what they've written, see if you agree with it, and then you can ask them questions about it, *you can try and persuade them if you think something different*' (L4)

In order to facilitate students' engagement with counter-arguing during this lesson, he had pairs of students talking together and comparing their results, 'finding which statement they agree the most with ' and 'which statement the are the least sure about' (L4). Yet, this activity took only a very small amount of time, and the group-work discussion switched to a whole class discussion due to time limitations. The first time that James had managed to model counter-argument and explicate the importance of providing alternative views was during Lesson 6. As he instructed students, they had to first find the appropriate evidence to support the view they were given and then consider evidence that would counter the views of the other groups.

85 You've got a red, blue or green hat on. That's your view point. Find something here [worksheet, Appendix F, Lesson 6] that will help you justify that; back it up. But then think about what the other two colours have got; think about what's on here that they're going to pick. Is there anything else on here that you could use to rubbish what they pick? Or can you think of something yourself that you can use to rubbish what they pick?
86 S: Rubbish? As in argue?
87 And put it down. Say it's not right. And what you are doing here is that you're arguing and counter-arguing and this is what happens in a debate […]
95 So you've got to think about what they are going to say about their argument and then think about how you can...rubbish it, how you can put it down, how you can say that's not the case because…. Is that all right? It's quite challenging and this is what you do when you argue about anything. You put forward your case you listen to someone else's case and you try to persuade them that you are right. And they try to persuade you *they* are right. (L6)

As James explained to his students, counter-arguments require the construction of an argument and simultaneously the careful consideration of the appropriate information that can serve as evidence for a position and against an alternative one. As a consequence, counter-argument is an epistemic action with a higher epistemic load that can be very challenging for the students (Kuhn, 2005; Glassner & Schwarz, 2005). In fact, the demands of constructing counter-arguments for the students, may have being counter-productive to James' attempts to incorporate this aspect or argumentation to his lessons since, according to James, successful science teaching and learning is dependent upon creating lessons where engagement and challenge are appropriately balanced for the students (J1). Emphasising counter-argument would be overly challenging for his students and would result to them being unengaged with the tasks in hand. What is more, his inconsistent use of 'Counter-Argument' and 'Prompts for Counter-Argument' supports the view that providing alternative viewpoints and supporting them with counter-evidence is not one of the aspects of argumentation that James specifically aimed to address in his argumentation lessons. This is also supported by the way he modelled argument, with the first time of modelling counter-argument being present in Lesson 6 and then again in Lesson 13, the last lesson observed.

Overall, James' classroom talk during argumentation instruction addressed the three epistemic process of construction, justification and evaluation of knowledge claims through various epistemic operations. He managed to prompt students to engage in constructing their knowledge through prompts for argument, description and evidence. His views of argumentation seemed to influence his discursive practices as he placed emphasis on the justificatory aspect of argumentation through 'Justification' and 'Prompts for Justification'. Finally, he was able to engage students in evaluative processes, especially through his use of 'Counter-Argument' and 'Prompts for Evaluation', as his use of 'Evaluation' often was found to be of an IRE pattern. James' classroom talk during non-argumentation lessons is explored in the following sections.

6.5 Epistemic Features of James' Classroom Talk During Non-Argumentation Instruction

The 7 non-argumentation lessons observed by James during the school year were transcribed and analysed based on the same framework of epistemic operations applied in the analysis of argumentation lessons. The results are presented in Tables 6.6 and 6.7.

Table 6.6: Epistemic operations performed by James during non-argumentation lessons

	Coding References (%)	**Group-work**	**Whole-class**
Provides evidence	83 (10.3)	52	31
Evaluation	73 (9.1)	54	19
Justification	66 (8.2)	24	32
Description	64 (8)	17	47
Generalisation	33 (4.2)	13	20
Explanation	23 (2.9)	10	13
Definition	20 (2.5)	5	15
Exemplification	21 (2.6)	7	14
Modelling	17 (2.1)	3	14
Counter-argument	8 (1)	6	2
Compare and contrast	14 (1.7)	4	10
Argument	11 (1.4)	6	5
Analogies/Metaphors	6 (0.7)	3	3
Prediction	2 (0.2)	1	1

Table 6.7: Epistemic operations prompted by James during non-argumentation lessons

	Coding References (%)	**Group-work**	**Whole-class**
Prompts for Evidence	147 (18.5)	115	32
Prompts for Justification	59 (7.4)	36	23
Prompts for Description	31 (3.9)	15	16
Prompts for Evaluation	30 (3.8)	22	8
Prompts for Argument	29 (3.6)	19	10
Prompts for Prediction	29 (3.6)	16	13
Prompts for Comparison	16 (2)	8	8
Prompts for Modelling	11 (1.4)	10	1
Prompts for Definition	6 (0.7)	2	4
Prompts for Classification	3 (0.4)	1	2
Prompts for Counter-Argument	1 (0.1)	1	0

6.5.1 CONSTRUCTING KNOWLEDGE CLAIMS: 'PROVIDING AND PROMPTING FOR EVIDENCE', 'DESCRIPTION' AND 'GENERALISATION'

6.5.1.1 'Provides Evidence', 'Description' and 'Generalisation'

As can be seen in Tables 6.6 and 6.7, epistemic operations such as 'Description', 'Generalisation' and 'Provides Evidence' were the most common ones used during non-argumentation lessons. These epistemic operations were used in a way similar to that presented for argumentation lessons, which was to introduce students to new ideas and establish a common knowledge base for the students to use in the activities to follow. For instance, in Lesson 9 James used 'Provides Evidence', 'Description' and 'Definition' to inform students about the function of voltmeters and ammeters that they would have to use in their practical investigations during that lesson.

…as you go round that circuit, in that circuit, that circle, should be the ammeter. Connected in that circuit, if you trace it around with your finger you should have the bulb, the battery and the ammeter. The voltmeter is connected separately. It is not part of that main loop. It's actually on a separate loop, which goes from the one side of the bulb out and then back to the other side of the bulb. OK?	*Description*
That's called a parallel connection, so the voltmeter is connected in parallel and the ammeter is connected in series. […] the voltmeter measures voltage, in volts. The units are volts. It measures voltage in volts, ok?	*Provides Evidence*
And voltage is the energy supply, if you like, of the circuit, it's the push, it's the force that makes the electricity flow around the circuit, ok?	*Definition*
The ammeter measures current in Amps, the units are amps and	*Provides Evidence*
current is the flow, it's the flow around the circuit, it's what's actually flowing around the circuit.	*Definition*
So, the ammeter measures the flow round the circuit and the voltmeter measures the push, the energy supply making that flow happen	*Generalisation*

(L9)

'Generalisation', was another epistemic operation James utilised to provide information to the students. 'Generalisation' was used mostly during whole-class interactions (60%), as was 'Description' (73%). For instance, during Lesson 1 James discussed with students how they could decide which is the best graph to use based on the data they had, and at the end he restated that 'if you are plotting words against numbers it's probably going to be a bar chart; if its numbers against numbers it's a line graph' (L1), providing a generalisation of how are students to decide how to construct their graphs.

6.5.1.2 'Explanation' and 'Argument'

The epistemic operation of 'Explanation' was present in 23 instances in the 7 lessons, most of which in Lesson 1 (4 coding references) and Lesson 11 (7 coding references). These two lessons were content-based, compared to the other ordinary lessons observed, which included practical investigations, such as Lessons 7, 8 and 9. The nature of the units taught seemed to determine the extent to which the epistemic operation of 'Explanation' was used. Lesson 1 for instance focused on a socio-scientific issue (Smoking and Addictions), which was more likely to include the discussion and explanation of concepts such as explaining how the levels of nicotine in a person's blood influence their cravings for smoking. The following is an explanation James provided to students in Lesson 1 while discussing the connection between smoking and bad health. In this case, the epistemic operation of 'Argument' (marked in italics) has also been identified, used to support the claim that smoking is bad for health, which was the main objective of the particular lesson and was written on the board throughout the lesson.

> 'It's a correlation. It just, it's a link, an apparent link. *However, because they had analysed using machines like the one I have on my left, what is in tobacco smoke, they knew what it was in it, the chemicals that were in it and they tested those chemicals in laboratories on living things, they had enough evidence to prove that correlation wasn't just a correlation, in fact, tobacco smoke causes those conditions*. So, what's a correlation? It's an apparent link. Does it prove the two things that link, one causes the other? No it doesn't. Ice-cream, eating ice-cream does not cause hay fever but there is a correlation between the two. How do we know tobacco smoke is so bad for you? Because of correlations when you look at populations but also because of analysing tobacco smoke and testing the ingredients on animals'

As in the case of argumentation lessons, the use of 'Explanation' and 'Argument' seemed to be inter-related. 'Argument' was identified 11 times in the 7 non-argumentation lessons observed (Table 6.6). From those, four coding references came from Lesson 1 and three in Lesson 11 (Appendix H). The presence of 'Argument' and 'Prompts for Argument' in Lesson 1 could be due to the fact that, as James mentioned, he originally planned to organise and teach the unit on ‘Smoking and Addictions’ based on the framework of argumentation, but eventually did not due to time constraints that prevented him from gathering the material he would need (field notes, 17/9/2009). However, it seems that even though he originally characterised the lesson as non-argumentation, when asked again at the end of the lesson he mentioned that there was ‘some argumentation there’ (field notes, 17/9/2009) as students had the opportunity to consider and compare data to see how it was concluded that smoking is a bad habit. These comments show that James used some of the ideas he might have considered for planning the particular lesson as argument-based, although there is no explicit mention of terminology specific to argumentation, such as argument and counter-argument, as in the 6 argumentation lessons he taught.

Lesson 12, a practical lesson, had the most ‘Prompts for Argument’ in non-argumentation lessons (10 instances, Appendix H). These focused on encouraging students to consider what would be the best way to organise their experiments to find which of four solutions was the most acidic, and why. Lesson 11, a content-based lesson, focused on forces and was a follow-up of an argumentation lesson taught the previous week. During this lesson, although there was no mention of any argument-related terminology – besides the word ‘evidence’ – James did provide arguments and prompted students to create their own arguments four times, whilst rotating the four groups of the class, and overseeing their group-work. For example, while talking to a group he prompted students to argue that the planets provided on their worksheet (Appendix G) are not of the same size, and helped one of the students express that argument in terms of gravity and mass (utterance 159).

143	*How can you tell they’re not the same size? Is there anything on the piece of paper that gives it away?*	*Prompts for Argument*
144	S1: Because that’s 11.6 Newtons so that means,	
145	S2: That’s smaller [Moon], that’s bigger [Venus], that’s smaller than that [Mercury] but bigger than that [Moon], and the Earth is the biggest.	
146	OK, what’s ‘that’? You’re a bit vague.	Prompts for Evidence/Information
147	S2: Hm?	
148	You’re a bit vague; you’ve got to be more precise.	
149	S2: OK. The moon is the smallest,	
150	How can you tell?	Prompts for Justification

151 S2: It has the least effect on gravity, and...
152 Least effect on?
153 S2: Weight by gravity, I'm confused.
154 What produces weight?
155 S2: Mass. Wait, no, yes.
156 And?
157 S2: Gravity.
158 *Right. So if [the] mass of this person stays the same in all these different places, try and say it again, try and explain it.* — *Prompts for Argument*
159 S2: OK. So, the moon is the smallest because it has the least amount of gravity on the mass.

Then, James went to a different group, which were off task, and used the example of a pencil-case on the table to engage them in a discussion of the forces acting on the pencil-case.

214 Are there any other forces acting on the pencil case?
215 S3: No cause it's not moving. Is there any up-thrust
216 […]
217 S3: It's not moving at any sides.
218 So what does that tell you?
219 S3: There's no force.
220 James: Careful. It tells you that there's no *overall* force.
221 S3: Overall force, yeah.
222 Now if you've got the weight going down and there's no overall force, there must be something going up as well.
223 S4: Yeah. Is it up-thrust?
224 Like up-thrust; the reaction. *So you've got two forces acting on this pencil case, one going down; one going up. They've got the same size but in opposite directions so they cancel each other out so the forces are balanced so the pencil case is standing still. And that's true for that person on each of those different planets, yeah? 'Cause they're standing on the planet, but the planets are different.* Look carefully, the planets are different. — Explanation Modelling
225 S4: Yeah but apparently there's only gravity on certain planets.
226 *All mass produces gravity. So there will be gravity on each of those planets. But what, look at the mass look at the weight figures and it tells you something about the size, the amount of mass the planets have got.* Which is the largest…? — Argument
227 S4: But the mass doesn't change.
228 Which is the biggest planet?
229 Students: Earth.
230 S4: Mercury.
231 S5: Venus.

232 How do you know it's Mercury?
233 S3: Because it's got 40 Newtons so it weights the most.
234 S5: Venus.
235 Is that the most?
236 S3: Oh no, 90.
237 S4: Venus.
238 90 [Newtons]. So on,
239 S6: That's the most gravity.
240 *On Venus this person has got 10 kilos of mass as a weight of 90 Newtons. So the gravity produced by Venus acts on that person's mass makes 90 Newtons of weight. Happy with that? Same mass different planet, 40 Newtons so the planet [Mercury] must be smaller 'cause gravity is less.* So that's what you've got to try and show on your force diagram. — Argument

In the example above, James not only provided an explanation of why an object remains still on the table but he also used the epistemic operation of 'Modelling' to talk about abstract constructs, such as forces. The thematic category of 'Modelling' was applied every time the teacher was attempting to make more concrete abstract notions such as chemical equations or constructs as gravity or forces. In particular, during Lessons 2 and 11 James made explicit attempts to engage students in modelling the forces acting on an object such as a cube (Lesson 2) or of an alien on different planets (Lesson 11). In Lesson 11, there were 8 instances where the teacher provided a model of a concept through his talk.

> 'When you draw a force diagram, so when you represent forces as arrows, drawn with a ruler, in other words, when you use a model to represent reality of forces, you don't have to draw the object as it appears. You can simplify the object. In fact scientists simplify objects all the time, so in a force diagram you can represent your object as a simple shape and in fact you can reduce them to a point in space. This represents the centre of gravity [points to dot on the board] of the object, OK? We can actually reduce Cefor [the alien] from this to this. For the purposes of our force diagram'
>
> (L11)

In the example above, James, provided a model of the forces acting on the alien and was reflective of this process at the same time, making the link between modelling and science.

6.5.2 Justifying Knowledge Claims: Providing and Prompting for Justification

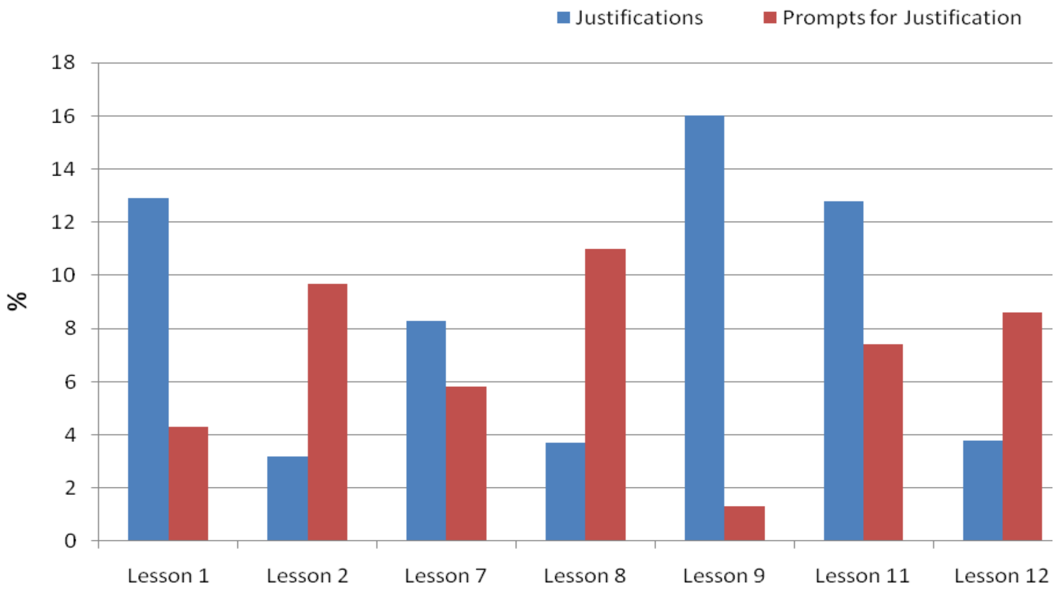
The epistemic operations of 'Justification' and 'Prompts for Justification' were present in all of the non-argumentation lessons observed. James used 'Justification' both during group-work activities and during whole-class discussions (Table 6.7). An example of 'Prompts for Justification' is provided below from Lesson 2. Students were provided with weighting scales (one for each group) and a piece of graph paper each, and were asked to consider how they would be able to use these materials to determine the connection between pressure, weight and surface area. The following is a discussion that took place in one of the groups while James was sitting with them listening to what they were discussing.

127 S4: You know when you stand on one foot yeah, is it that you put more weight on the other foot, that's why you sink?
128 *OK, why then?*
129 S5: Look, my weight is on one foot [stands on the scale and moves]
130 S4: Because you are putting more weight onto the other one.
131 So the weight, S5 is standing on his feet so it's not my weight that makes me sink, what is it?
132 S5: Is it the...
133 S4: …the pressure.
134 The pressure. *Why the pressure?*
135 S4: Ehm...
136 OK, think about it. Think about what we did. What were the two factors? My weight and the area that I've got on the ground; both feet or one foot. So what you need to know is your weight and the area through which your weight is pushing on the ground.

At this point of the lesson, James was more interested in listening to the students' ideas and attempted to make these ideas explicit through prompting students to justify their thinking. His contributions in utterances 128 and 134 prompted students to provide justifications for their beliefs as to ascertain whether students understood how the concepts of pressure and surface area could relate.

A detailed examination of the content of the justificatory comments found in James' talk during ordinary science teaching, shows that the nature of justifications provided were either procedural or content-based, as was in argument-based instruction. In particular, from the 56 times that a justification was provided during non-argumentation lessons, 31 instances (55%) focused on a content-related issue such as ‘your weight would be enormous cause Jupiter is super-massive so its gravity is huge compared with the gravity on Earth’ (L11) with the rest being of a procedural nature such as ‘cause you might already know the answer; but you’re only going to test one each cause you haven’t got time to do all three [experiments]’ (L8). Figure 6.8 presents a summary of the justificatory comments that James used during his non-argumentation lessons.

Figure 6.8: Justificatory talk found in James’ non-argumentation lessons



Lesson 9 had the most instances of ‘Justification’ from all the non-argumentation lessons (Figure 6.8) with 16% of the epistemic operations found in that lesson, were identified as ‘Justification’. However, almost half of those instances included a justification of a procedural nature addressing issues such as why a circuit did not work. The procedural nature of justifications found is attributed to the practical nature of the lesson (Appendix G). What is more, ‘Prompts for Justification’ during Lesson 9 was used only once. This would suggest that during Lesson 9 James did not attempt to engage his students in the justificatory aspect of scientific practices.

6.5.3 Evaluating Knowledge claims: 'Proving and Prompting for Evaluation' and 'Counter-Argument'

6.5.3.1 'Evaluation' and 'Prompts for Evaluation'

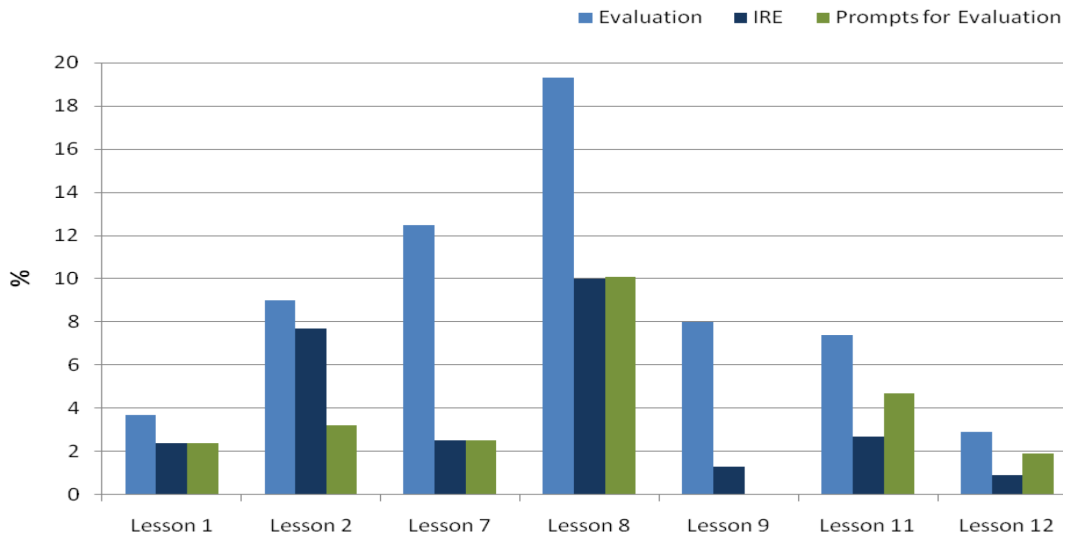
The epistemic operation of 'Evaluation' was used in ordinary science lessons in similar ways to those identified in argumentation lessons presented earlier. Many of the instances of 'Evaluation' identified were found to follow the IRE pattern. In fact, 34 of the 73 'Evaluation' instances (47%) found in non-argumentation lessons followed the IRE pattern of interaction. Only in some cases, James was found to spend more time within a group and it was then that the discussion he initiated with the students became epistemically relevant in terms of evaluative processes.

412 S1: Why is there a knife? [projected on the board]
413 Why is there a knife? Fabulous question. Why is there a knife?
[…]
422 S2: It's friction...
423 OK, unlucky. It's not friction. Friction comes into knives cause they are moving objects; yes, that knife is going to get hot cause that guy is rubbing it against that sharpening stick but friction, what was this lesson about? How about you...
424 Students: Pressure.

(L2)

In the extract above, James elaborated on the students' answer, providing reasons for why the answer was not correct and helping students understand how the lesson connects to everyday life situations, such as using a knife. Figure 6.9 presents the percentage of instances that evaluative comments were provided by James during each of his non-argumentation lessons.

Figure 6.9: Evaluative comments provided by James in non-argumentation lessons



As illustrated in Figure 6.9, Lesson 8 contained the most 'Prompts for Evaluation'. During that lesson, students were given thermometers amongst other apparatus and James rotated the groups asking students if they had figured out how they were going to use the thermometers to provide an answer to the question 'which metal is the most reactive'. Specifically, James questioned students about their actions and he provided the appropriate feedback or evaluation to guide students to the right direction. Moreover, during Lesson 8 he held a discussion with students about creating graphs based on the data students would collect from their practical work, and considered with students criteria for creating graphs.

27 Here's a graph. And if you want to tell the story of what happened and you've plotted data on the graph to help you do that, *is it better to have lots of points on the graph or just one?*
28 S: Lots.
29 Why?

(L8)

The most evaluative comments were met in Lessons 7 and 8, which were practical lessons (Appendix G/H). As in the case of 'Justification' in Lesson 9, due to the practical nature of Lessons 7 and 8, the evaluative comments identified were mostly of a procedural nature when checking on how the students were dealing with equipment, how they were proceeding with their experiments and in general, the behaviour of students during a practical lesson. Particularly, in Lesson 8 the evaluative comments provided were about the way the students were planning their investigation and the way in which they intended to use the apparatus to collect and record their data.

James' approach to organising and teaching practical lessons might be one of the reasons that most evaluative comments are found in this type of science lessons. That is, during the practical lessons observed, James provided students with the materials they could use and asked them to organise their investigations in order to answer a question, usually written on the board throughout the lesson, as he did in Lessons 8 and 9. In this way, students had the opportunity to be critical, as shown in the two extracts below.

> 'On your own, you need to think about how you are going to do it, what data you are going to record, how you are going to record it, and how you are going to try and make the data, the evidence, you are going to sue to solve the problem more reliable'
>
> (L8)

> 'You'll have to be a detective here. You've got to think about all the things that could go wrong and then try to put them right one at a time. And if you're still stuck, ask me'
>
> (L9)

This approach to practical lessons was consistent with his views on practical work and decision-making, as presented based on his interviews, in Section 6.3.2. Moreover, in Lesson 7, which was a practical on the chemical reactions of carbonates with acids, the final activity was a modelling activity of the chemical equation between one of the metal carbonates used during the practical (zinc carbonate) and hydrochloric acid.

> 'What's wrong with my model? Lots of things. OK, in reality these particles – the hydrochloric acid particles – are in a solution; they've been resolved in water so they've being moving around; that [carbonate solution] represents something that's dissolved – that's ok. That [CO_2] represents a gas so that will be whizzing all over the place and that one [H_2O] represents water that will be moving around cause it's in liquid form'
>
> (L7)

James gave students tiddlywinks of different colours and asked them to model the reactants and products of the chemical equation. At the end of this modelling activity he reflected on what the models represented comparing the models of the chemical equation to the actual products and reactants of the reaction, as shown in the extract above.

The epistemic operation of ‘Prompts for Evaluation’ seemed to have a more epistemic function in James’ talk, compared to ‘Evaluation’ since it was then that students were given the opportunity to evaluate a situation or their own actions. However, prompting students to engage in a process of evaluation was a discursive practice that James did not engage as much as providing evaluations himself (with the exemption of Lesson 8, Figure 6.9). In addition, although a number of ‘Prompts for Evaluation’ were identified in James’ talk during non-argumentation lessons, these often were not explored any further with James usually asking students the question of ‘are you happy with that’ in his attempt to make sure that the students are listening to him rather than actively engaging them in evaluative processes of what their classmates or James’ had said.

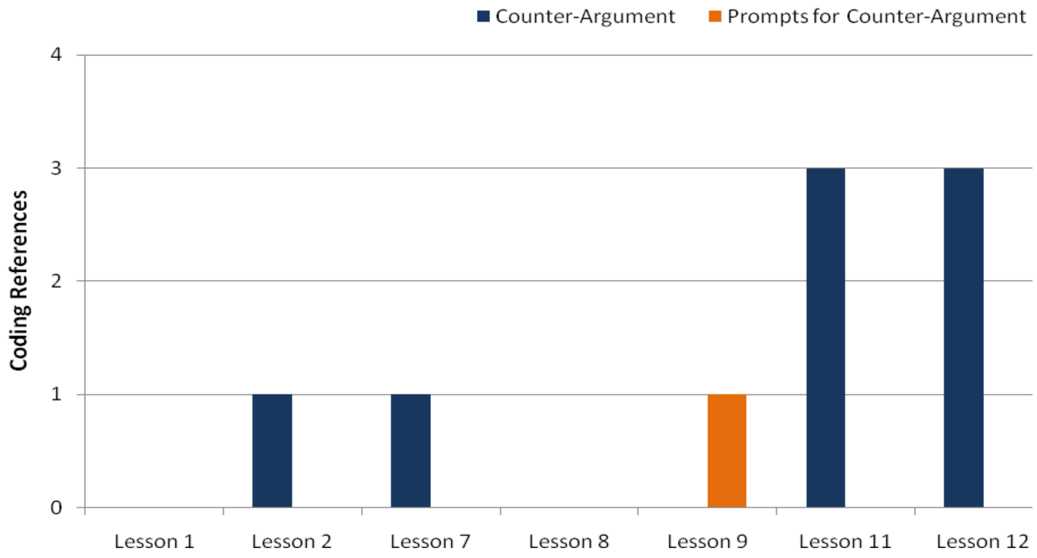
6.5.3.2 ‘Counter-Argument’

The use of the epistemic operation of ‘Counter-argument’ was also identified in James’ classroom talk during non-argumentation lessons, although to quite a limited extent. For instance, during Lesson 8 while talking to a group of students he prompted them to consider whether their results were sufficient to answer the original question of the investigation (utterance 389) and when S4 responded, James implied that one set of data for each of the metals investigated was not enough to ensure the reliability of the student’s results, suggesting in this way a counter-position (utterances 393-397).

388 S4: Is that all right sir? [his graph]
389 *You tell me. Are you happy with it? OK. So you’ve got, your axes are linear, they got up in even steps, OK. Can you tell, can you answer the question using that data? The original question?*
390 S4: What was the question?
391 Which one of those metals is the most reactive?
392 S4: Yes. Magnesium. I’ll write that.
393 *Can you though? Can you tell from that data? Is that one set of data?*
394 S4: No.
395 Yeah. Is that one set for each metal?
396 S4: Yes.
397 *OK. Is that reliable?*
398 S4: Yeah, ehm, no.
399 *So can you tell from that data?*
400 S4: Because she hold it [test tube] in her hands [while measuring the temperature]
401 *Can you tell from that data? What would you need to do to be able to answer the question?*
402 S4: Test it a few more times. (L8)

Figure 6.10 shows how limited the presentation of alternatives to the students was when James was not teaching based on argumentation.

Figure 6.10: 'Counter-argument' and 'Prompts for counter-argument' in James' ordinary lessons



'Counter-Argument' was found mostly in Lessons 11 and 12, with three instances of a counter-position in each. The following excerpt from Lesson 12 presents how James suggested a counter-position when discussing with a group of students different ways of using the apparatus available to decide which of four solutions provided (rain water, acid rain, water with carbon dioxide, water with sulphur dioxide) was the most acidic.

82 So, how could you use that to work out which of these was the most acidic and which was the least?
83 S1: We'll see which one is...
84 S2: Whichever fizzes it's acidic.
85 *OK. Careful. What if they are all acidic but…*
86 S2: Then they will all fizz.
87 *…but one's more acidic?*
88 S1, 2: The one that fizzes more.
89 S3: The one that fizzes more, you need to make a fair test.
90 *OK, how can you make a judgement about how much it's fizzing?*
91 S4: Look at it.
92 S1: How high it goes in the tube.

93 OK, various ways you may do that.
94 S4: Or timing.

James encouraged students to consider not only which solution was acidic but also to make an evaluative judgement on which solution was more or less acidic using both epistemic operations of ‘Counter-argument’ in utterances 85-87 and ‘Prompts for Evaluation’ in utterance 90 (in italics). The epistemic operation of ‘Counter-Argument’ in this extract was based on a suggestion of an alternative position to the one that S1 and S2 proposed in utterances 83-84. This would suggest that James’ did not make any conscious attempts to counter-argue with the students and was not explicitly using this discursive action in his talk. What is more, ‘Prompts for Counter-Argument’, appeared only once throughout the 7 ordinary lessons observed (Figure 6.9). This was in Lesson 9 were James asked students to consider how they could make their investigations more reliable by collecting a number of data instead of just a few. Even in this case, there is only an implicit suggestion of an alternative position that students could consider, as shown below.

105 OK. Now, what are you going to record? How many data sets do you need to record? How many pairs of data do you need to record?
106 S: One.
107 *One is enough, is it?*
108 S: Oh no, no, no. We do it with three batteries, two batteries, one battery. Then we can do it with two bulbs…

Overall, the discursive actions of James during non-argumentation lessons were influenced by the nature of the lessons in which he was engaging with students. That is, during practical lessons, such as Lessons 7, 8 and 12, the epistemic operations identified aiming at justifying and evaluating knowledge claims were often of a procedural nature, focusing on the equipment that students would use to conduct their investigations and the reasons they had decided to follow one way over another. Moreover, evaluative processes were mostly present through the epistemic operation of ‘Prompts for Evaluation’, whereas aspects such as counter-arguing were essentially not used as part of his classroom talk. The similarities and differences in the classroom talk of argumentation and non-argumentation lessons are explored in the next section.

6.6 Comparing the epistemic operations of James' argumentation and non-argumentation lessons

Up to this point, the various epistemic operations found in both argumentation and non-argumentation lessons have been presented, as well as the way they were used to construct, justify and evaluate knowledge claims. This section aims to present a comparison between the epistemic features of argumentation and non-argumentation lessons in order to establish commonalities and differences and answer the second research question of this thesis, which focuses on identifying any changes in the epistemic discourse of James over the period of the school year.

On the whole, the types of epistemic operations found in James' classroom talk during argumentation and non-argumentation lessons were similar. In this respect there was not any difference between the argumentation and the non-argumentation lessons observed. What differed in the classroom talk of argumentation lessons as compared to ordinary science teaching was the frequency of the discursive actions used. That is, epistemic operations such as 'Description', 'Generalisation' and 'Provides Evidence' were used more often in non-argumentation lessons. For instance, the discursive action of 'Prompts for Evidence' was utilised in non-argumentation lessons 21 times on average in each lesson compared to an average of 13 times in argumentation lessons (Tables 6.5 and 6.7; Appendix H).

In argument-based instruction, James used epistemic operations such as 'Description', 'Definition', 'Exemplification', 'Provides Evidence', 'Generalisation' and 'Explanation' mostly during whole-class discussions in order to provide the contextual information and understanding necessary for students to engage in discussions and argument-building activities. The use of epistemic operations such as 'Provides Evidence' and 'Description' facilitated students' participation in the constructive process of scientific practices and are thus an important component of James' classroom talk. Figures 6.11 and 6.12 present the various epistemic operations used in argumentation and non-argumentation lessons, respectively. Epistemic operations were grouped based on the discussion of the two types of lessons presented in Sections 6.4 and 6.5 of this chapter.

Figure 6.11: James' epistemic operations in ***6 argumentation lessons*** *based on the epistemic practices of construction, justification and evaluation of knowledge claims*

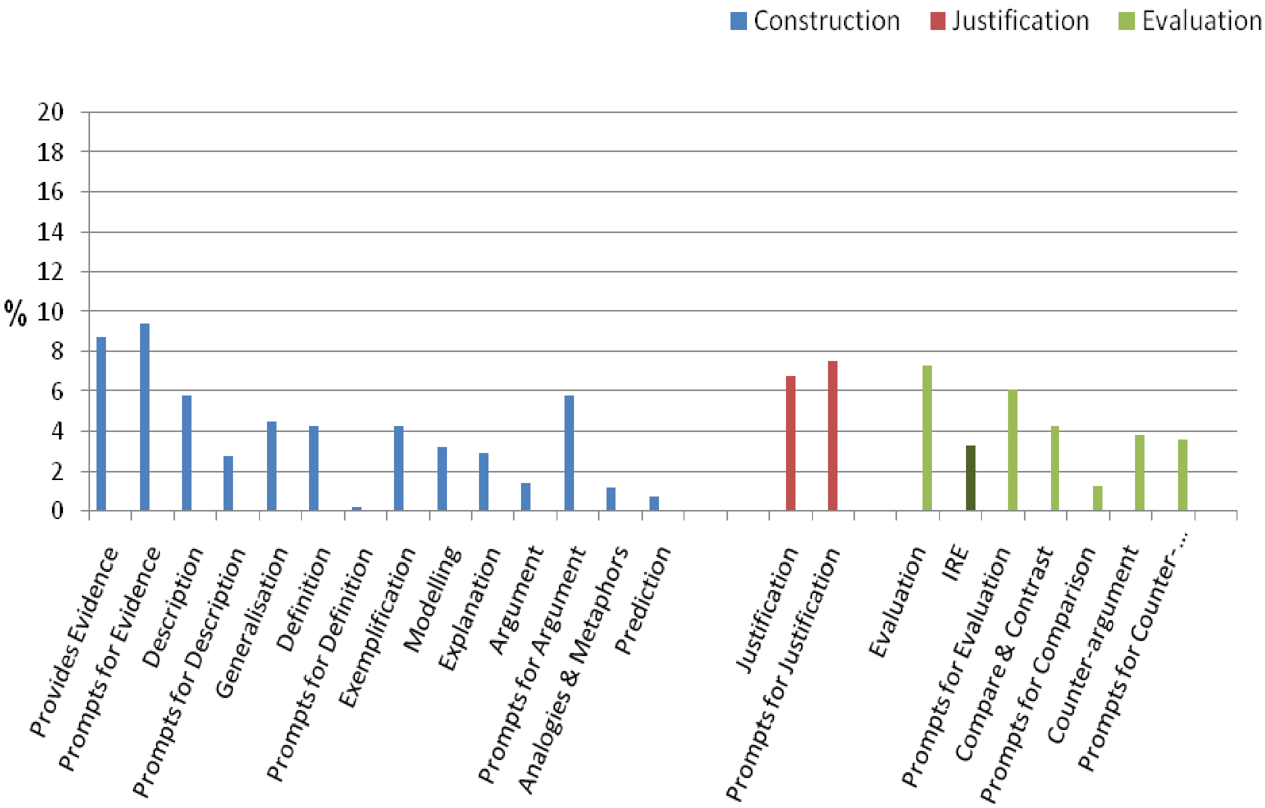
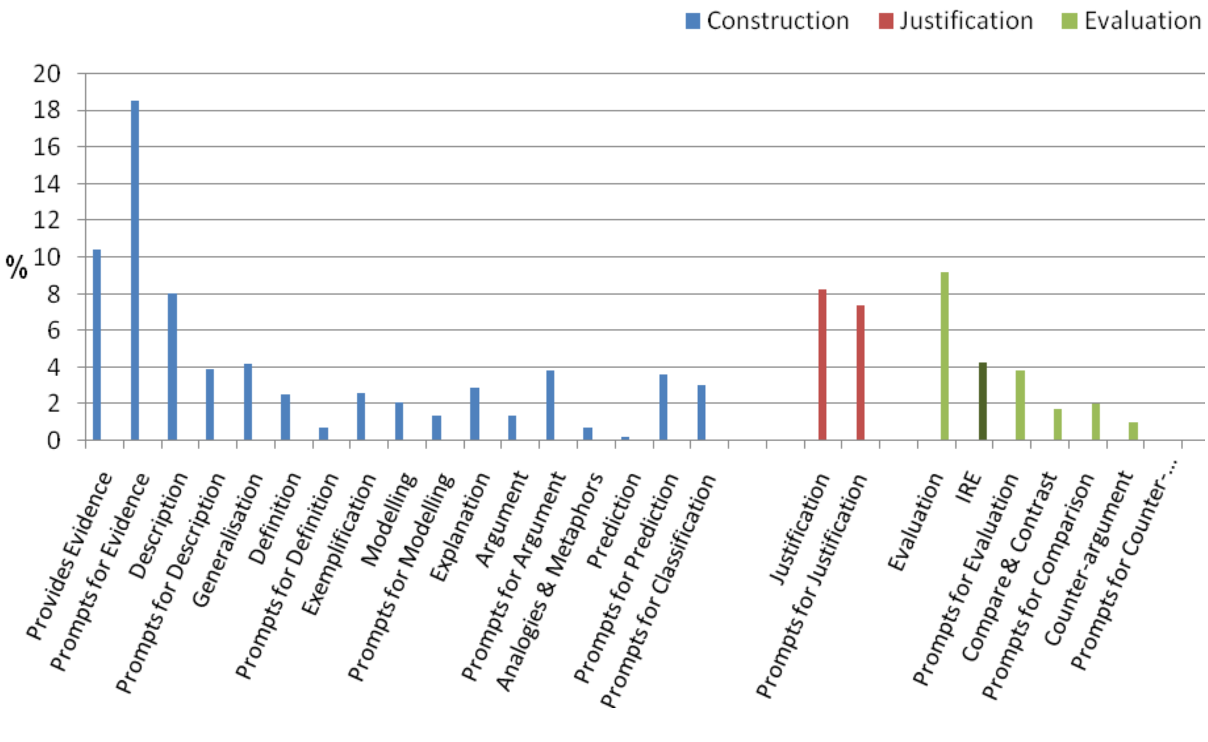


Figure 6.12: James' epistemic operations in ***7 non-argumentation lessons*** *based on the epistemic practices of construction, justification and evaluation of knowledge claims*



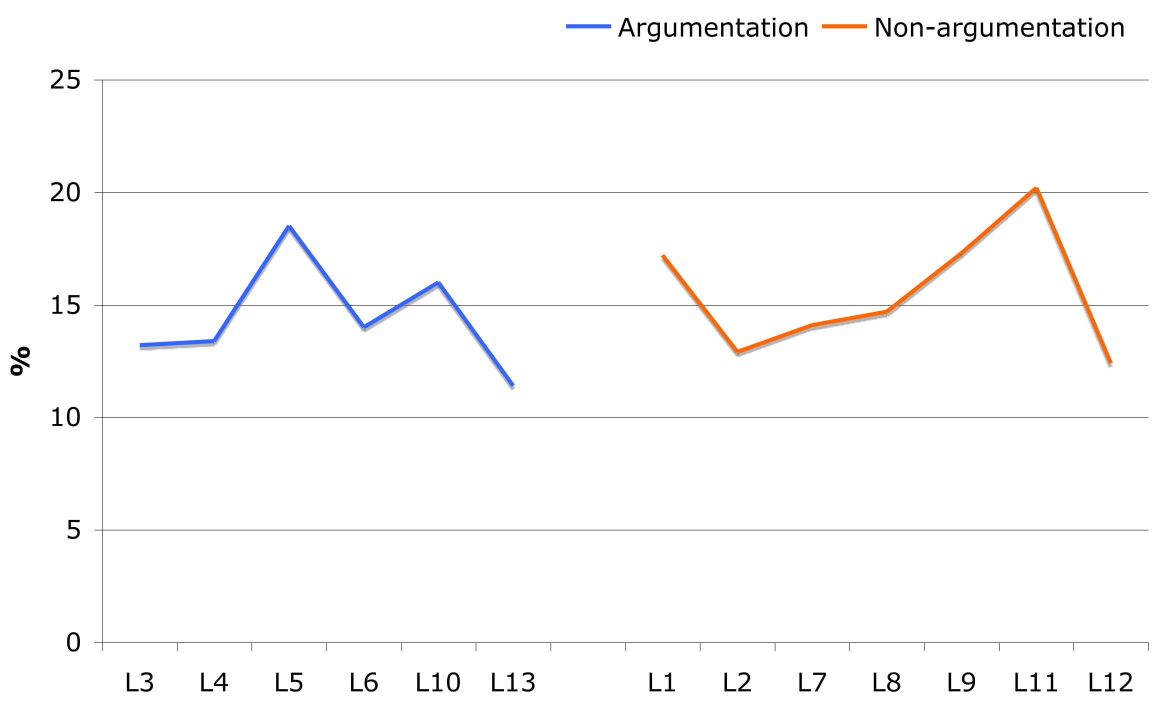
In ordinary science teaching, providing factual information seemed to be the overall objective of James' discursive actions, since he did not attempt to prompt students to use the information he had given them, as he did in argument-based instruction. Instead, he mainly focused on prompting students for evidence or information. In non-argumentation lessons, James used the same epistemic operations but without aiming at building on the students' knowledge in the same way that he did in argument-based instruction. Namely, in argument-based instruction, the epistemic operations that formed part of the process of constructing knowledge claims were not the end-result of the lessons. Rather, the epistemic operations used to construct knowledge claims in argumentation lessons were the means for guiding students towards not only constructing their own knowledge of scientific phenomena such as gravity, weight and photosynthesis, but also for engaging in evaluative and justificatory processes. As a result, James was able to present to students the various facets of the epistemic practice of science, as opposed to focusing only on declarative knowledge.

A comparison of Figure 6.12 to Figure 6.11, demonstrates how during non-argumentation lessons the classroom talk shifted towards providing and prompting for evidence on the expense of more epistemic talk such as making comparisons, providing and prompting for counter-arguments and alternative positions and, prompting students to evaluate and critique their own and other students' views. That is, epistemic operations that focused on evaluation and critique were not present in the teacher's non-argumentation lessons (see also Figure 6.10). The comparison based on Figures 6.11 and 6.12 would suggest that the use of argumentation as a framework for teaching and learning science was instrumental in presenting the evaluative aspects of the scientific practices and making them part of the talk and thinking that took place in the science classroom.

The aspect of James' classroom talk that seemed to remain consistent in argumentation and non-argumentation lessons was justification. As shown by his definitions of argumentation (Section 6.3.3), James focused on the justificatory nature of argumentation. Additionally, the ability to 'justify a viewpoint' was an issue that emerged in most of James' argumentation lessons and it was the main way in which he made the distinction between an argumentation and non-argumentation lesson (field notes, 17/09/2009; 6/05/2010; 1/07/2010). James seemed to use 'Justification' consistently across the school year, which would suggest that his teaching practices were not influenced by argumentation. However, the fact that 71% of the justificatory comments made by James were content-based during argumentation instruction compared to the 56% in non-argumentation lessons, and the fact that he was using ‘why’ more in argumentation than non-argumentation lessons (Appendix H), would suggest that the quality of justificatory comments made was higher in argumentation lessons.

Figure 6.13 presents the overall instances that a justificatory comment had been made by James across the 13 lessons observed (including all instances of ‘Justification’ and ‘Prompts for Justification’).

Figure 6.13: Justificatory comments made by James over the school year



As shown in Figure 6.13, the overall use of justificatory comments in James’ talk varies between 10% and 20% of the total of epistemic operations identified in each lesson. Across the school year, in both types of lessons, there did not seem to be an increase in the use of ‘Justification’ or ‘Prompts for Justification’. What seemed to be happening was that the use of justificatory talk was context-dependent. Namely, the nature of each lesson – within argumentation and non-argumentation lessons – seemed to influence the use of this type of talk, although as mentioned previously, during argumentation lessons the quality of justificatory comments seemed to be higher.

James' focus on the justificatory nature of argumentation, led him consider the notion of evidence extensively in his lessons. There was a consistent effort to engage students in the collection and interpretation of evidence, which they could then use to support their answers (most of the lessons observed – both argumentation and 'ordinary' – involved the generation of a graph from which the students had to extract evidence in support of the main issue/question of the lesson). What is more, during the last two observations in Lessons 12 and 13, he mentioned the word 'evidence' 26 and 21 times respectively – more than in any other lessons – prompting in this way students to think about the evidence they had gathered, how they could use them and how they could make them more reliable. The emphasis on the word 'evidence' provides support to the view that James chose to focus on the aspect of argumentation that is concerned with the nature and role of evidence.

This view is also supported by the fact that he was concerned with his students' ability to engage successfully in argumentation instruction. During informal conversations with James, at the end or before of his lesson observations, often he expressed his concerns about the students' ability to follow the lessons taught and to stay on-task, especially when having to talk or work in groups (field notes, 1/10/2009; 15/10/2009; 5/11/2009). For instance, at the end of Lesson 4, James stated that he was not satisfied with the way the lesson developed, as many students were not able to stay on-task, which he attributed to the level of difficulty that students had with some of the statements provided. The last activity of Lesson 4 required student pairs to share their answers with another pair and discuss their opinions. James' instruction to the whole-class was that 'you have to read what they've [the other pair] written, see if you agree with it, and then you can ask them questions about it, you can try and persuade them if you think something different' (utterance 324, L4). Yet, when James went around the groups to listen to students' discussions, his talk was mostly procedural making sure students had a pair to talk to and that they were actually engaging with the activity.

Another example of mentioning the students' ability levels was based on Lesson 3. When the teacher described Lesson 3 during his first interview, he mentioned that students had both to utilise evidence in justifying their selection of statements from the chart flow (Appendix F) and, go through an evaluative process of selecting which of those statements was best. However, the implementation of the argumentation lesson eventually focused on justification rather than evaluation of knowledge claims. An explanation for this change was the level of challenge that the activity imposed on the students. As the teacher mentioned, many of the students found Lesson 3 'too hard and they switched off' (J1). In fact, as he mentioned during this interview he had the opportunity to teach the same lesson with a different, higher ability group of Year 9 students in another school (as part of his AST role, Section 6.2). During this lesson, the opportunity to engage in a process of evaluation of knowledge claims was provided by the students themselves, who were able to argue against all the statements provided in the flow chart and the lesson 'then became more than just choosing which statement and justifying your choice; it then became [about] making that statement better' (J1).

As a result, James' perceptions of his students' ability levels, guided him towards focusing on aspects of argumentation students would be able to engage in, such as the use of empirical data as evidence they could use to justify their opinions. The influence of James' perceptions of his students' ability levels on his teaching practices could be one of the reasons that his classroom talk focused on the construction and justification of knowledge claims accounting for the presence of epistemic operations, such as 'Proving Evidence', 'Prompts for Evidence' 'Justification' and 'Prompts for Justification', and the inconsistent use of 'Counter-Argument' and 'Prompts for Counter-Argument' (Figure 6.11) in argumentation lessons, and, the limited presence of 'Counter-Argument' in non-argumentation lessons (see Appendix H and Figure 6.10).

Another concern put forward by James was the mismatch between the way that students were formally assessed and the conceptual development or other possible benefits that argumentation may had on students, and the way that these benefits could be made visible beyond the level of the science classroom. As James maintained a 'schism' (J1) existed between the way students were assessed formally and new perspectives on teaching and learning science in a way that 'the impression that you have of these kids and the way the kids are actually measured by the system and the impression the system has of them' are very different and difficult to overcome.

On the whole, based on the analysis of classroom talk provided in this chapter, the epistemic talk that James utilised as part of his teaching across the 13 lessons observed did not change or develop. That is, there were no epistemic features of his classroom talk that he used in argumentation lessons that became (more) evident in his non-argumentation lessons. Although he was able to use meta-language related to argumentation such as 'evidence' in his non-argumentation lessons, his use of justificatory comments across the school year as shown in Figure 6.13, were consistent across the two types of lessons. This would indicate that the discursive actions identified in his lessons and the epistemic talk that took place during these lessons was context-specific. That is, operations that aimed to initiate a discussion or engage students in a discursive episode depended on the nature of the lesson and the aims that the teacher had for that lesson. For instance, 'Prompts for Counter-Argument' were present in only two of the six argumentation lessons and most of those prompts are utilised in Lesson 6, which is planned with a specific emphasis on counter-argument. Finally, the teacher's perceptions of his students' ability to engage in argumentation lessons and his own views of argumentation influenced his discursive practices.

6.7 Summary

James used an array of epistemic operations in his argumentation lessons in order to construct, justify and evaluate knowledge claims. From these three aspects of epistemic practices, the ones he placed more emphasis on was construction and justification of knowledge claims. Moreover, his ability to incorporate argumentation activities in his teaching practices depended on his views of argumentation as a practice of science and as a teaching approach, and, to his views of the students' ability and willingness to participate in argument-based activities. When teaching science not based on argumentation, James focused mainly on constructing scientific knowledge with or for the students, based on epistemic operations of a lower 'epistemic forcefulness' (Siegel, 1995), than those found in argumentation-based instruction. In addition, during non-argumentation lessons, James placed less emphasis on evaluation and counter-argument. This would suggest that using argumentation as an instructional approach was able to advance the epistemic discourse within James' science classroom. What is more, the different ways in which James attempted to provide information and the content necessary for creating and supporting arguments, as shown by his use of epistemic operations in Section 6.4.1 suggest that he considered content knowledge as an important requirement in successful argument construction.

As James mentioned during his second interview, when asked whether he felt he had gained anything from using argumentation to teach, he stated how much more aware he was of issues about the nature of scientific practices and knowledge and how that awareness was for him at that point more obvious in the way he planned his lessons.

> ‘I think it gives you a bit of an awareness of what’s important. I mean with How Science Works coming on the agenda after Curriculum 2000, the notion of science as, important bits of science being about, being argumentation essentially, and understanding the notion of evidence, I mean that’s being on the agenda for a while so this project has just kinda made that more explicit. *So it has taught me to keep that awareness; I do seem to have that awareness more than I used to have.* But that’s what we’re trying to do and the, ehm, whenever I think about the content, it used to be about the content and that would be the sort of starting point for planning. *I suppose it is to some extent but more so it’s the way of the journey and the notion of, the orchestration of the lesson, the kind of the activities you’re asking them to do*’
>
> (J2)

At that point, James seemed to realise the importance of the activities in which he presented his students with the content of science, instead of focusing on content itself. This awareness was evident in his use of meta-language, such as ‘evidence’ in his latter lessons observed, but was not present for other aspects of argumentation in his classroom talk. This would suggest that changing or adopting teaching practices is a slow and long process, which has to be consistently addressed.

CHAPTER 7

CASE STUDY 2

AMY AND HER YEAR 10 CLASS ENGAGING IN EPISTEMIC TALK

7.1 INTRODUCTION

This chapter aims to provide a description and analysis of the discursive practices of the second teacher that participated in this research project. This analysis is undertaken in order to provide an answer to the first and second research questions of this study, which are, firstly, to examine the epistemic aspects of science teachers' classroom talk during argumentation and non-argumentation instruction and secondly, to compare the two types of lessons, searching for any changes in the teacher's practices. In order to provide answers to these two questions, this chapter first presents the background information and general description of the teacher and students. Moreover, the teacher's views about science, argumentation and the practices of teaching and learning are explored to provide a basis for the analysis of the teacher's classroom talk. Then, the analysis of the epistemic features of the teacher's argumentation and non-argumentation lessons is provided, based on the same framework of 'epistemic operations' applied in the lessons of the first science teacher. Then, a comparison between the two types of lessons is presented and finally, some conclusions for the epistemic practices of the science teacher are discussed.

7.2 AMY AND HER YEAR 10 GROUP

Amy was one of the two lead teachers of her school, participating in the T2L project. At the start of the T2L project, she was a Newly Qualified Teacher (NQT) teaching Biology and Chemistry in year groups 9, 10 and 11. Amy held a science degree in Human Biology and a Postgraduate Certificate of Education (PGCE). The 2009-2010 school year – the year the lesson observations for this study were conducted – was the third year Amy was teaching at the same school. At that point she was the Science Specialism Coordinator teaching Biology, Chemistry and Physics in Year 10 and Year 11 and Biology in Key Stage 5. The school was a mixed comprehensive, science specialist school located in the north-east of Greater London. Students were grouped based on ability sets. Amy was willing to participate in this study when asked and was part of the initial pilot study contacted in the spring/summer terms of 2008-2009. The student group with which Amy was observed teaching was a Year 10 class (14-15 years old) of 29 students (16 girls and 13 boys) in a middle set (B and C grades). This Year group did not participate in any other argumentation lessons before the observations begun. The science curriculum taught was 21st Century Science, and Amy was observed teaching lessons from modules B1: You and your genes, C1: Air quality and P1: The Earth in the Universe.

The first observation was conducted in October 2009 and the last observation in June 2010. During that time, Amy taught four argumentation lessons and eight non-argumentation lessons were observed, two of which were lessons focusing on revision for the students' upcoming exams at the time (see Appendix C for a timeline of data collection). Amy taught this Year 10 class in the same science lab three times a week, on Mondays (9.45-10.35), Wednesdays (14.10-15.00) and Fridays (11.40-12.30). Communication with the teacher was conducted mainly through emails and occasionally through telephone. Amy usually suggested dates for observations, mostly based on the types of activities that the students would be undertaking. As in the first case study, for each of the lessons observed the teacher was asked to characterise each lesson recorded as 'argumentation' or 'non-argumentation'. Finally, Amy was interviewed twice throughout the year. The first interview took place in January 2009 and the second interview in July 2010. Table 7.8 provides a summary of the 12 lessons observed and the epistemic operations that each of these lessons could provide opportunities for.

Table 7.8: A synopsis of Amy's 12 lessons

	Argumentation	Non-argumentation	Epistemic operations
L1 21/10/09	**Embryo selection** Students were provided with case studies (for and against embryo selection) and asked to work in pairs to argue for their case study. They then worked in groups to counter-argue each position and finally, they were asked to form and express their own opinion on IVF treatment and embryo selection.		- Argument - Counter-Argument - Justification - Explanation - Provides Evidence
L2 23/10/09		**Genes-Cloning** Students were presented with a picture of identical twins and asked to find any differences between them. Then, they discussed terms such as 'unspecified cells', 'asexual reproduction' and 'artificial cloning' before they worked through a worksheet with questions on the same topic.	- Description - Definition - Explanation - Justification - Provides Evidence
L3 2/12/09		**Plate-tectonics** The objective of this lesson was for students to summarise the events that take place at plate boundaries. To do that, students were given a set of information cards they had to put in a sequence to describe events such as tectonic plates, constructive plate margin, destructive plate margin, volcanoes and earthquakes.	- Description - Classification - Provides Evidence - Evaluation
L4 7/12/09		**Geo-hazards in the news** Students were put in groups and assigned one geo-hazard each (earthquakes, volcano eruptions etc.). They were asked to create a poster using laptops for presenting to the rest of the class what the problem was, how it affected people and what governments should do to prevent these.	- Provides Evidence - Argument - Evaluation - Compare & Contrast

	Argumentation	Non-argumentation	Epistemic operations
L5 13/01/10	**What killed the dinosaurs?** Students were presented with information/evidence which they were asked to categorise into competing theories about the extinction of dinosaurs and then in groups, develop their own arguments on the issue.		- Argument - Counter-Argument - Compare & Contrast - Justification - Explanation - Evaluation - Provides Evidence
L6 5/02/10		**Handling data and plotting graphs** Students were given a worksheet entitled *Children in Iceland can't blow bubbles*, on which they needed to work during the lesson. This included a set of data for which students needed to consider *outliers*, *range of results*, *error bars* and *real difference*.	- Provides Evidence - Description - Justification - Argument
L7 12/03/10	**Acid rain-Pollution** Students were presented with information about acid rain in different countries and were asked to work in groups and provide answers to the questions: 'Was it fair to call Britain the "dirty man of Europe"? and 'Is the acid rain crisis really over'?		- Provides Evidence - Argument - Evaluation - Counter-Argument - Justification - Compare & Contrast
L8 15/03/10		**Improving air quality** Students were given an issue on air quality and were asked to create posters in groups to present the problem and possible solutions. Students worked on their posters throughout this lesson while the teacher went around supervising their work and answering questions.	- Provides Evidence - Argument - Description - Procedural talk

	Argumentation	Non-argumentation	Epistemic operations
L9 7/05/10		**Revision Lesson (C1)** Students were revising unit C1 (Air quality) for their upcoming exams. The teacher projected questions on the board which students had to answer and then evaluate each other's' answers. The students were asked to individually go through the unit and make a revision plan.	- Explanation - Description - Evaluation - Provides Evidence - Exemplification
L10 10/05/10		**Revision Lesson (P1)** Students were revising for unit P1 (The Earth and the Universe) in their end of May exams. Firstly, they had a quiz with revision questions projected on the board and then they were asked to go through the unit and write down all the concepts they had difficulty with for the teacher to use in further revision sessions.	- Description - Explanation - Justification - Provides Evidence - Evaluation
L11 23/06/10		**Antibiotic Investigation Plotting data** Students participated in an investigation about antibiotics. They were given a table of results and were asked to determine what happens to the growth of bacteria as the strength of the antibiotic increases by plotting and interpreting a graph.	- Provides Evidence - Description - Prediction - Compare & Contrast - Evaluation
L12 30/06/10	**Data Analysis: breathing rate** Students were presented with a set of data on the relationship between pulse rate and breathing rate and were asked to analyse and interpret statements based on this data (IDEAS, Osborne et al., 2004b).		- Argument - Counter-Argument - Evaluation - Compare & Contrast - Justification - Provides Evidence

7.3 Amy's Views About the Nature of Science, Teaching and Learning, and Argumentation

Amy's views on the NOS, her perspectives on teaching and learning and her ideas about the nature of argumentation and its implementation in science education are presented in this section.

7.3.1 Amy's Views of the Nature of Scientific Practices and Knowledge and the Teaching of NOS Aspects

The aspects of NOS discussed with Amy included scientific practices, theories and the nature and role of evidence in the practice of science. From both interviews conducted, a view of science as the study that aims to provide an 'understanding of the world and everything around us' (A2) emerged. Amy also placed emphasis on 'discovering how things work' and 'why', 'investigations' and finally, how the knowledge acquired through scientific practices can then be applied and developed in the areas of technology and medicine. When talking about science, Amy tended to make the link with school science and the parts of NOS included in the curriculum. For example, she mentioned how scientists engage in investigations to collect data. She then went on to talk not only about the processes of practical investigation students are required to engage in as part of the curriculum but also about activities and discussions on:

> 'how scientific theories are assessed in terms of peer review, publications and scientific journals; […] students have to understand how scientists once they've collected this data and they've got a conclusion what do they then do with it; how do other scientists find out their findings and their theories. […] Also looking at things like [the] difference between observations, explanations, data, and linking observations together using your imagination to come up with a theory; the idea that theories can change and evolve with different evidence'
>
> (A2)[10]

[10] A1 and A2 denote the first and second teacher interview accordingly.

The NOS aspects Amy mentioned above, such as the nature of theories, explanations and observation, creativity, and social influences of scientists, were part of the curriculum specifications she had to follow (21st Century Science). This emphasis was based on 'ideas about science' in the curriculum and formed her own perspectives on how scientific knowledge should be presented to students, as provided in the following description she gave when asked why should teachers be presenting to students the NOS aspects she mentioned above.

> '[…] rather than teaching them science as this is fact, it's teaching them this is a theory. And they now need to understand what we mean by theory […] how scientists come up with theories and why we sometimes change our theories or why some people don't always agree with a scientific theory. So it's getting the students used to the idea that what we're teaching them is a theory, is what we think it's happening, it's the most likely explanation at the moment, and this is the evidence that we have for it, but it is possible to change if we come up with new evidence. […] So we are trying now to get away from presenting it as a factual piece of information, as this is how it works, [and] rather *this is what we think happens, this is how we think it works*.
>
> (A1)

As can be seen in the above extract, and the text in italics, Amy emphasised the need to present the tentative aspect of scientific knowledge to students but also to stress that the knowledge acquired so far is based on evidence. The relationship between scientific theories and evidence was another aspect of the NOS discussed, which was in agreement with her views of how the nature of scientific theories and explanations could be presented to students. In particular, in both interviews she remarked on the connection between the notions of 'theory' and 'explanation' maintaining that:

> 'a theory explains data or explains an observation […] It may be that the theory is correct and it may be an easy theory to prove, but it may be a theory where there's conflicting evidence and it's a less solid theory'.
>
> (A1)

She held the same view during the second interview, where she defined a theory as 'an idea put forward by someone' and that the evidence supporting the theory could be linked together to form an explanation of a phenomenon or 'an idea of how something works or why something is the way it is' (A2).

The role of evidence in scientific investigations and the formation of scientific theories was further discussed by Amy, who considered the nature of evidence as data that would help towards the creation of new scientific theories, supporting or contradicting claims and at times, discrediting other scientific theories. She also provided an example of how the role of evidence can be presented in the classroom, from an argumentation lesson she had taught (Lesson 5, Table 7.8). During that lesson, students were presented with two alternative theories to account for the extinction of dinosaurs and were asked to use a set of evidence to argue for and against each of the theories. In this way, students were able to argue for the two possible explanations discussed and use evidence in that process to qualify their arguments. However, they were also given the opportunity to realise that the possible scientific explanations were 'not necessarily rock solid, […] not the definitive truth' (A1) since both had evidence for and against them. By providing this example of an argumentation lesson when discussing the nature and role of evidence in science she also demonstrated she was able to consider the link between the practice of argumentation and NOS issues, and was able to reflect on their inter-relationship. In fact, when she was asked to provide her views on the nature of argumentation she made an explicit connection to the way that argumentation as a scientific process is utilised in the creation and establishment of scientific theories, as illustrated in the extract below.

> '[…] your argument in a way is how we develop scientific theories, you've used evidence, you've used data you've used observations to base your argument on and this is what's supporting your argument. So in a way, this is how we develop scientific theories; we use evidence, data, observations to, and link them together to come forward with a theory'
>
> (A1)

Overall, the interview data would suggest that Amy held an informed understanding of issues relating to the nature of scientific knowledge and the practice of science. She considered the explanatory purpose of the scientific practice and she viewed scientific knowledge as formed through creative and social processes, and finally, as subject to change in light of new evidence and ideas. What is more, Amy made the connection between NOS aspects and ways in which these can be represented in the science classroom. Her perspectives on teaching and learning science and how NOS and argumentation could be part of this are presented next.

7.3.2 AMY'S BELIEFS ABOUT TEACHING AND LEARNING: GIVING STUDENTS CONTROL AND OWNERSHIP OF THEIR LEARNING

Two main themes were mentioned as important for students' learning in general, and in science in particular, by Amy. Firstly, she believed that students learn in different styles and ways. Thus, it was important for the teacher to be aware of that and take it into consideration when planning and teaching science. For that reason, as she mentioned, she attempted to include a variety of activities in her lessons as to maintain her students' engagement levels and 'try and meet everyone's [learning] needs' (A1). Maintaining her students' interest in the lessons and having them engaging with the tasks in hand, was a major concern for Amy. In fact, she pointed out the importance of giving control to the students over their own learning experiences as a means towards achieving and developing engagement and interest during a lesson. Secondly, the notion of 'ownership' was mentioned on a number of occasions when talking about how students learn. Amy believed that students should be provided with opportunities to be active learners. As she stated:

> 'It's this idea of ownership. […] For example, [I showed them] a picture of a girl who's overdosed on ecstasy lying on a hospital bed and I sort of ask them, where-why-how, those sort of questions, so they start, *they* start formulating their ideas about the picture, they come up with the idea that she's overdosed, she's ill, you know on life support, What's happening to the body? […] They're coming up with all these questions […] that they then want answered, which means they then have to take part in the lesson in order to find the answers' (A1)

Even though the notion of ownership was considered as an important facet of students' learning, Amy did acknowledge that often students were accustomed to working in a more 'traditional' way. This traditional way of teaching would be characterised by the teacher giving detailed instructions and dominating the lesson, instead of students being provided with the opportunities to organise their own learning and work 'independently'. Within the description of the lesson provided in the extract above, she was the one guiding the whole-class discussion with students, which shows that she was also using this more 'traditional' way of teaching science, at times. This would suggest that even though she considered ownership an important element for student learning, she nonetheless, attempted to maintain some control over the learning process. According to

Amy, 'ownership' could also be developed and sustained by students whilst doing practical work and was thus a way she attempted to organise and teach lessons involving practical investigations.

> '[…] Rather than being so prescriptive with the practical work you say [to students] "Right, this is the aim of what you're trying to achieve during this practical, here's the equipment, go and do it". And actually them thinking about what equipment I need, what I'm trying to get out of this, what's the point. And they start then asking themselves these questions, what's the point of me doing this, what I'm trying to achieve. So if they don't know how to set it up, they've got to really-really think about what are they achieving, what outcome do they want from this practical before they even think about putting the apparatus together. It really gets them thinking and I think that's a really good way of them to learn'
>
> (A1)

During practical investigations where students are allowed and encouraged to make their own decisions on how to approach their investigation, students are more likely to think deeply about the processes they are engaging in since 'if they come up with the ideas they are more likely to invest their time in it and invest a bit more thinking' (A1). This perspective on teaching and learning was also evident in the lessons Amy was observed teaching. Students were encouraged and given the opportunities to ask questions, and she used those opportunities to discuss with the students and help them develop their understanding. For example, in Lesson 10 – a revision lesson – she mentioned to students that she would allow them to choose which was the best way for them to revise during the lesson. What is more, students seemed to feel comfortable enough in the classroom to initiate discussions and ask Amy to further explain the issues under investigation (Lesson 2, 10 and 12). For instance, in Lesson 12, students were shown a short YouTube clip of a female marathon runner who had difficulty breathing and finishing her race. During that lesson, students started questioning the runner's behaviour, asking why and what was happening to her, questions which Amy then utilised as the grounds for initiating a whole class discussion with students about the relationship between breathing rate and pulse rate, which was one of the objectives of the lesson.

Overall, Amy's beliefs of teaching and learning reflected the need for active participation and engagement on the part of the students for learning to occur. This included allowing students to make decisions during the course of the lesson, providing examples and tasks that would cover the students' different types of learning (i.e. computer simulations, video clips, group-work activities, writing tasks) and finally, giving students a voice in the classroom. These views, although not specific to argumentation instruction, could support Amy's attempts to implement argumentation as part of her teaching practices. In the next part, Amy's views on the nature and use of argumentation in the science classroom are presented.

7.3.3 Amy's Views on the Nature and Use of Argumentation in Science Education

Argumentation was perceived by Amy as a dialogic process of constructing knowledge and understanding by providing an idea or theory and then using evidence to support that idea, as shown in the two extracts below.

> 'Argumentation is pupils using dialogue to explain a theory, to explain their ideas or it could be to put forward a theory, argue a theory, show the evidence for a theory and it could also be a way of showing their understanding as well, so if they can, if they can not only state a scientific theory but if they can give it evidence to support it, it's showing a high level of understanding cause they're explaining why that evidence supports that theory, why it goes with that theory and not with another'
>
> (A1)

> [Argumentation is] a method of getting pupils to either understand information or to process information, to develop their own thoughts'
>
> (A2)

As can be seen in the extracts above, she perceived argumentation as a way of developing students' thinking skills and conceptual understanding. Especially at the end of the project, when asked to describe how she believed she utilised argumentation as part of her teaching, Amy characterised it as a 'vehicle' and 'method' for learning and focused mainly on argumentation as a teaching approach. This would suggest that at that point she had a clearer idea about how to use argumentation as a teaching approach, compared to the beginning of the school year. Moreover, she maintained that argumentation should be considered as 'just one way of arriving at that [learning] point' and not as a separate lesson with different objectives and outcomes from customary, which would further suggest she was more aware of argumentation as a general approach to science teaching.

The dialogic nature of argumentation as a way of communicating ideas was a recurrent theme in her interviews and the main way in which she differentiated between argumentation lessons and ordinary science teaching. In fact, engagement in dialogue through the use of argumentation activities was perceived as beneficial for students' learning. In particular, Amy referred to the competitive nature of argumentation as motivating students to provide several reasons for, or against, a viewpoint, which would be distinct to the more ordinary form of lessons where students would have to provide a written answer to questions without anyone challenging their views at that point. In contrast, during dialogic argumentation students could express their views but they could also challenge and counter-argue each other's viewpoints. Additionally, Amy stressed the importance of developing communication skills through argumentation, especially for students with literacy problems as it could facilitate the externalisation and communication of their ideas, clearly and more frequently, than in normal science lessons.

The students' ability to engage in argumentation activities was one of the issues she considered as problematic in her attempts to use argument. Specifically, Amy mentioned how students in low ability groups lacked the skills and willingness to participate in argumentation activities. She maintained that low ability students often did not possess the necessary skills of critical thinking and listening that were required when having to ask questions about the issue discussed and argue for or against a position. As she mentioned, especially when these students were asked to counter-argue, 'they do not really listen to each other's arguments, they are more concerned with doing their own bit and then, they don't care what they others are saying' (A2). These low ability students' negative attitude towards argument-based instruction was attributed to their 'mentality', in the sense that they were not accustomed to participating in activities such as counter-arguing and posing each other questions. Moreover, students seemed not willing or able to consider views outside their own beliefs and 'they kind of stay fixed at that [their] point, they don't try and see the wider view' (A2). Consequently, she believed that counter-argument with lower-ability groups was an area of her teaching she needed to further develop and plan activities that lower-achieving students could participate in successfully and productively.

On the whole, Amy supported the view that one of the most important aspects of using argumentation to teach science is its ability to develop students' beliefs of how scientific knowledge is created and established. Students need to develop an understanding and 'habits of mind' of being critical and willing to consider alternative viewpoints and evidence, which teaching through argumentation may contribute towards. This perception of argumentation and its benefits for science teaching is important because it demonstrates Amy's awareness of the need to engage students in activities and thinking processes that are similar to those that scientists would undertake in their investigations. Nevertheless, she also stressed that presenting science in this way was challenging, as students are not put in situations where they have to be critical of what and how they are learning. What is more, she maintained that through argument-based instruction, students could develop an evaluative stance towards scientific knowledge. Finally, an important issue that affected the way she developed and implemented argumentation lessons was her perception of the difficulty of planning argumentation lessons based on content-based units. In particular, in both of her interviews she mentioned how organising argumentation lessons around ethical or socio-scientific issues was much easier for her rather than on content-specific lessons, where she had difficulty identifying possible points of view or arguments based on specific content knowledge she had to teach. This difficulty with planning lessons based on argumentation could be the reason that throughout the school year that she was observed she only taught 4 argumentation lessons, of which one was based on a socio-scientific issue (Lesson 1: Embryo selection) and only one was content-based (Lesson 7: Acid Rain). The ways in which she taught these lessons and the nature of the classroom talk during the argumentation lessons are presented in full in the following section.

7.4 Epistemic Features of Amy's Classroom Talk During Argumentation Instruction

Throughout the course of the 2009-2010 school year, Amy taught four argumentation lessons (Table 7.8). These lessons were transcribed and coded using the same framework of epistemic operations presented in Case Study 1 (Appendix C1). As in the first case study, the thematic categories applied were (a) epistemic operations *performed* by the teacher, and operations the teacher *prompted* students to engage in, (b) the nature of the talk that was taking place (procedural or content-based) and finally, (c) the type of the activities in which teacher and students were participating. Tables 7.9 and 7.10 provide a synopsis of the epistemic operations found in Amy's talk during her argumentation lessons and the type of activity in which they were performed (group-work or whole-class).

Table 7.9: Epistemic operations performed by Amy in argumentation lessons

	Coding References (%)		
		Group-work	Whole class
Justification	57 (10.6)	23	31
Evaluation	57 (10.6)	36	14
Provides Evidence	43 (8)	22	21
Generalisation	35 (6.5)	23	12
Description	21 (3.9)	1	20
Explanation	16 (3)	4	12
Exemplification	14 (2.6)	4	10
Argument	12 (2.2)	8	4
Compare & Contrast	7 (1.3)	2	5
Definition	7 (1.3)	0	7
Counter-argument	6 (1.1)	4	2
Analogies & Metaphors	2 (0.4)	0	2
Modelling	1 (0.2)	0	1

Table 7.10: Amy's prompts of epistemic operations in argumentation lessons

	Coding References (%)		
		Group-work	Whole class
Prompts for Justification	59 (10.9)	46	13
Prompts for Argument	53 (9.8)	40	13
Prompts for Evaluation	53 (9.8)	42	11
Prompts for Evidence	45 (8.3)	24	21
Prompts for Counter-Argument	13 (2.4)	11	2
Prompts for Comparison	12 (2.2)	5	7
Prompts for Classification	11 (2)	9	2
Prompts for Description	9 (1.6)	8	1
Prompts for Definition	5 (0.9)	1	4
Prompts for Prediction	2 (0.4)	2	0

In order to explore the epistemic features of Amy's classroom talk, the epistemic operations identified in her talk, as presented in the two tables above, are discussed. These are organised based on the epistemic practices of construction, justification, evaluation and communication of scientific knowledge (Kelly, 2008).

7.4.1 Constructing Knowledge Claims: 'Provides Evidence', 'Generalisation', 'Explanation' and 'Argument'

The construction of scientific knowledge was achieved mainly through the epistemic operations of 'Provides Evidence', 'Generalisation' and to a smaller extent through epistemic operations such as 'Explanation' and 'Argument'. These are presented and discussed in the following sections.

7.4.1.1 'Provides Evidence' and 'Prompts for Evidence'

The epistemic operation of providing evidence or information is one of the strongest features of epistemic operations found in Amy's lessons. As can be seen in Tables 7.9 and 7.10, 'Provides Evidence' and 'Prompts for Evidence' were equally used amongst group-work and whole class interactions, which suggests that Amy wished to make sure that her students had the necessary information to engage actively and complete their tasks.

Specifically, 'Provides Evidence' was used when the teacher was giving students information that might be necessary for their tasks or when she reminded students of previous lessons. The latter was often the case for Amy, who tended to use argumentation lessons at the end of a unit, so as to engage students in activities that summarised and applied knowledge learnt in previous lessons (L1, L5 and L7). Moreover, 'Provides Evidence' and 'Prompts for Evidence' were used as a response to students' questions, for instance after a short video clip or picture was presented to the students. For example, in Lesson 12, Amy showed the students a video-clip of a female marathon runner that was struggling to get to the finish line, which triggered a number of questions by the students.

34 S1: I don't get it. Why are they doing this?
[…]
37 S1 asked a very good question. She said 'why'. Why are they running like that? Why are they doing that? S2? […]
40 S2: They've got no energy left […]
41 Right so there's a lack of energy there, ok. *So what does the body need energy for S2?*
45 […] *What'd you need...S3?*
46 S3: To move your muscles.
47 Right. To move your muscles, OK? So one use of energy in your body is to move your muscles. Right, *S2, how do you generate energy in your body*? What did you just say?
48 S2: Respiration?
49 Respiration, right. So respiration is a chemical reaction that releases energy in the body. OK?
51 […]Right, *S4 what'd you need for respiration*?
54 S5: Glucose.
55 S6: Oxygen.
[…]
59 Oxygen yeah, and glucose. […] So you need glucose and oxygen for respiration to release energy. So those marathon runners their body weren't getting enough energy, OK? There weren't big enough supplies of oxygen and glucose to keep their muscles moving normally. So what happened is because of that lack of energy their muscles couldn't contract properly and so how they moved started to change'

In this case, she used the request for an explanation by S1 in utterance 37 to initiate a whole-class discussion during which she prompted students for information (shown in italics) before she gave an explanation for the behaviour of the runner included in utterance 59. By requesting students for information she was able to share that information with the whole class, which she then synthesised into an explanation of the processes taking place in the runner's body as she run.

Moreover, 'Provides Evidence' was used the most in Lesson 5 (21 instances, Appendix J), which focused on the extinction of dinosaurs and the scientific theories that attempt to explain this event. In this case, Amy needed to provide students with the information they had covered in previous lessons about topics such as earthquakes and volcanoes and how they occur before allowing students to work on their arguments. These actions reaffirm that Amy was using the epistemic operation of 'Provides Evidence' and 'Prompts for Evidence' as a mechanism for establishing students' prior knowledge rather than constructing new knowledge during the argumentation lessons observed.

The nature and role of evidence for the practice of science was mentioned at the end of Lesson 7. Amy stressed how the objective of the lesson was the ways in which students approached and looked at the evidence they were given, and made the link between investigating evidence within a science context, like they had done during Lesson 7 and the importance of evaluating evidence in everyday life by saying:

> This lesson wasn't so much about looking at necessarily air pollution it was firstly working as a group and how well you work as a group together and secondly looking for evidence for things. Because all these newspaper articles that we read […] they are based on either speculation or evidence. And it's really important that you can tell the difference between evidence and just speculation, someone just coming up with something. […] If you can spot evidence like you started to do by sorting these cards then you can be very intelligent people because you can come up with informed decisions, ok? So you don't just say like we did at the beginning, "Oh that's not fair, it's a bit harsh to call Britain the dirty man of Europe". OK, […] *you can actually say "It wasn't fair because...".You can back up your opinion with an argument and people are more likely to listen to you if you can give evidence;* if you can have something solid behind what you're saying. OK? They are more likely to take what you're saying and listen to it and be persuaded by it'
>
> (L7)

In the extract above, Amy explicated the important role that evidence has in making a distinction between a guess and an informed decision based on evidence. In fact, during Lessons 5 and 7 she mentioned the word 'evidence' 71 times, emphasising in this way the importance of using evidence in argument construction. In the extract above, she also modelled the process of argument (shown in italics) as a claim and justification through evidence. The ways she utilised ‘Argument’ and ‘Prompts for Argument’ are further explored next.

7.4.1.2 ‘Argument’ and ‘Prompts for Argument’

The use of the epistemic operations of ‘Argument’ and ‘Prompts for Argument’ were also part of the way in which scientific knowledge was constructed during Amy’s argumentation lessons. ‘Argument’ was mostly used during group-work interactions (Table 7.9) since, as Amy was going around the groups and listened to the students’ arguments, she often engaged with them in the process of argument construction, as shown in the next extract from Lesson 5. In this case, Amy provided students of that group with an argument a different group had presented to her earlier in the lesson (in italics) and at the same time, she used evidence (types of rock) to support the argument that volcanic eruptions were the reason that caused the dinosaurs’ extinction.

283 S1: What can I say to back up this theory apart from the gas one?
284 Amy: Right, do we know a super volcano has happened?
285 S1: No.
286 Amy: Don’t we?
287 S2: Yes.
288 Yes. Why do we know?
289 S2: Because of all the layers.
290 Amy: Right, so we know from the rock type, so the igneous rock, we know how old the rock is, we know how much rock there is, so we know there must have being this huge volcanic eruption, yeah? But lots of them have happened. *So what one group was saying is that lots of volcanic eruptions have happened and we know they’ve happened so they’re more likely. An asteroid impact is very*-*very rare whereas they’re more likely so that’s [volcanic eruption] more likely to [have taken place]*

(L5)

The emphasis placed on the construction of arguments is evident by her use of ‘Prompts for Argument’, which was the second most frequent epistemic operation found in her prompts/questions towards students. 53 instances of ‘Prompts for Argument’ were found in the four argumentation lessons and the overwhelming majority of these were during group-work discussions (Table 7.10). In contrast, her use of ‘Argument’ was considerably less (12 coding references), although present in all argumentation lessons. This would suggest that Amy did not place emphasis on creating arguments herself but on encouraging her students to engage in argument construction. As Amy went around the groups, she encouraged students to construct their arguments through questioning them and asking them to state their arguments and their justifications. Often, the same prompt for argument was used repeatedly, as is the case of Lesson 12. During this lesson, students were given four statements and a graph (Appendix I) and were asked to work in groups of four to select which statement was best describing the graph and then 'explain their answer' by saying 'why' (L12).

328 What statement did you agree on?
329 S1: D [On the whole, those people with a higher breathing rate had a higher pulse rate].
330 Why did you all agree on that one?
331 S1: Because it covers all of the main events, like it mentions both factors and it don't say "all" and give a direct…[…]
332 S1: It's like on the whole.
333 So what does that "on the whole" mean?
334 S1: That there could be some that are not [inaudible]
335 Excellent, well done. So it identifies that not everyone fits the trend. Well done. So there's some outliers there. Why have you picked it over that one?

(L12)

During 'question and answer' sequences as the one presented in the extract above, Amy mainly requested for a position or a claim of the argument (as in utterance 328) and subsequently of a 'Prompt for Justification' (utterance 331) and/or 'Prompt for Evidence' (utterance 334) that would provide support to the students' argument/position. Thus, 'Prompts for Evidence' and/or 'Prompts for Justification' were an essential part of Amy's discussions with students during group-work. In this way she was also modelling argument as a claim supported by evidence, which were the two main elements of argument she prompted students to provide and, similar to the way she modelled argument in Lesson 7 (see extract on page 186).

Amy's attempts to prompt students to create their own arguments and take a position during these lessons was not restricted to the time that students were working in groups but also during whole-class interactions. For example, at the end of Lesson 1 she provided students with opposing arguments they could provide using religion as a reason [embryo selection is wrong because of religion or embryo selection is correct because of religion], after she had heard the different student groups' arguments about embryo selection.

> 'Some religious people might not agree with embryo selection because they believe that God created us and we shouldn't interfere in God's creation process but on the other hand, you can use religion as an argument for. Well, God gave us the intellect, the knowledge to look at genes, to be able to develop these technologies so we should use it'
>
> (L1)

During the time that Amy was addressing all students providing an argument, she modelled the process of argument construction for the students and gave them examples of how an argument should be constructed to be strong and convincing. Amy also modelled argument through the use of meta-language, explicitly stating the elements that a good argument should include.

> 'So remember any good argument, whether it's written or spoken, you are going to include reasons, you're going to include evidence and you're going to need persuasive language. Imagine that you're writing to someone and trying to persuade them to your way of thinking, ok? Why is your theory the better one?
>
> (L5)

In the example above, she had set up the criteria for a good argument as including reasons and evidence. At the same time, she emphasised that it was not only important that they used scientific content or facts but also the structure of their written answer needed to be in such a way that would be able to persuade others about the validity of the claim put forward.

7.4.1.3 'Explanation'

'Explanation' was another epistemic operation utilised during argumentation lessons. The fact that the topics that Amy chose to develop into argumentation lessons were socio-scientific such as the effects of air pollution and air quality (Lesson 1 and 7) or of a generic nature, such as dealing and interpreting data (Lesson 12) meant that often she was not addressing content knowledge that would require the explanation of constructs or processes of a scientific phenomenon. Nonetheless, 16 instances of an explanation were identified in the four argumentation lessons she taught, as in the example below from Lesson 12.

> ‘You need glucose and oxygen for respiration to release energy. So those marathon runners their body weren’t getting enough energy, OK? There weren’t big enough supplies of oxygen and glucose to keep their muscles moving normally. So what happened is because of that lack of energy their muscles couldn’t contract properly and so how they moved started to change. They can’t move as we would or how they did at the start of the race’
>
> (L12)

As in the first case study, where James seemed to use ‘Explanation’ and ‘Argument’ together, so in this case, Amy used these two epistemic operations together during Lesson 5, where the teacher was providing students with the possible explanations for the extinction of dinosaurs. In that case, Amy was explaining how one of the scientific theories about the impact of an asteroid would have caused the extinction of the earth, as shown below.

60 S: Miss, you know when it [the asteroid] hit in America?
61 In Mexico.
62 S: Yeah, but it spread all around yeah? How did the wave hit Australia and…
63 So what they think is one, there was this huge dust cloud, so it through up all this dust which would’ve covered the earth, so the clouds would’ve just covered the Earth, so just like the wind would carry it. That would’ve caused lighting strikes which could cause forest fires, it probably had a lot of poisonous chemicals in it which when it fell obviously it chocked them and tidal waves as so like tsunamis’

(L5)

In this case, Amy attempted to explain how the extinction of the dinosaurs by a huge asteroid collision would be possible by providing an ‘Argument’ in utterance 63.

7.4.1.4 ‘Generalisation’

The use of the epistemic operation of ‘Generalisation’ was a common aspect of Amy’s classroom talk, especially during group-work activities. ‘Generalisation’ was usually accompanied by the word ‘so’ and its function during a discussion was to repeat information or establish some common ground of knowledge for the students to use in order to be able to continue with their activities. As mentioned in Section 7.4.1.1, the function of Amy's argumentation lessons was for students to apply the knowledge they had from other lessons. Thus, the generalisations provided often were following students' answers to previous questions during whole-class discussions, as was the case in the extract presented from Lesson 12 (p.185). In that case, when students replied to her prompts for evidence she would then rephrase or restate what individual students said as a way of sharing OR reaffirming that information with the whole class (utterances 41, 47 and 51). Moreover, Amy utilised the epistemic operation of 'Generalisation' after she listened to the students' conversations whilst students worked in groups. For instance, in the following example from Lesson 1, she prompted students in a group to provide an argument against embryo selection (utterance 102) and she then rephrased the student's answers for all students of the group to hear and consider ('Generalisation' shown in italics).

102 So what were your points to them, what were you saying?
103 S1: They are basically killing all the embryos,
104 S2: They only want a child.
105 OK. *So killing lots of embryos, so essentially its murder*. Is that what, yeah?
106 S1: Yeah.
107 What else, S2 you just said something.
108 S2: Yeah, the only reason why they want to have the child is to be, for it to be a donor, so they might not have the same amount of love and affection for it.
109 *So the feelings of that child when it's born, how it might feel when it grows up learning that it's a donor.*

(L1)

The use of the epistemic operation of 'Generalisation' was an important feature of the teacher's classroom talk because of the way in which she used it to engage students in the learning process. Namely, by using students' comments and talk to provide 'Generalisations' to the students she was empowering the students' participation to the discussions taking place since their own thoughts, ideas or knowledge were used in the epistemic process of (re)constructing scientific knowledge for all students. By adopting this discursive action, Amy made her role complementary to that of the students' during the lessons observed whilst at the same time, she provided guidance towards the appropriate use of scientific terminology and helped students take into account other students' ideas in order to construct their arguments.

7.4.2 Justifying Knowledge Claims: 'Justification' and 'Prompts for Justification'

The epistemic process of justifying scientific knowledge claims was one of the most common features in Amy's classroom talk, both as she addressed the students as well as through the questions or prompts she posed to them. The next sections present how Amy used the epistemic operations of 'Justification' and 'Prompts for Justification' in the four argumentation lessons she taught.

7.4.2.1 'Justification'

The epistemic operation of 'Justification' was the second most frequent epistemic feature of Amy's classroom talk (Table 7.9). She provided a 'Justification' 54 times throughout the four argumentation lessons she taught, and her use of justificatory comments was consistent throughout the school year, except for the first lesson (Appendix J). Further examination of the nature of justificatory comments made showed that most justificatory comments were based on the scientific content discussed during each lesson. From the 57 times that Amy provided a justification, 35 were during content-related talk such as 'the reason why it's [the environment] recovering is that there is less pollution being released' (L7) or 'because there's evidence that supports the asteroid theory, that talks about why we think it's an asteroid' (L5). Justifications provided during procedural talk (22/57) were mainly whilst Amy was giving instructions to students for the activities to follow as in 'the reason being [for getting into groups of four] that one pair is going to be for embryo selection, the other pair is going to be against embryo selection' (L1).

7.4.2.2 'Prompts for Justification'

'Prompts for Justification' was another strong feature of the epistemic practices of Amy as she was consistently and persistently asking her students to explain or to justify their thinking and answers, and do so using evidence and 'persuasive language'.

> 'If I could stand here long enough and pick all of you, *all of you could give me a reason as to why you're standing where you are, which is this important part of backing up an argument*, ok? It's all very well saying I agree with something, or disagree with something, *but the ability to be able to justify where you are standing is something very highly intellectual*. OK? To be able to justify your argument, so very impressive, well done'
>
> (L1)

'Prompts for Justification' was the most common way Amy employed to challenge students' thinking, especially during group-work activities (78%). As with 'Prompts for Argument', the use of 'Prompts for Justification' was strongest in group-work interactions since it was then that most of the discussions were taking place between students and/or amongst students and Amy. The question 'why' was the main way through which Amy prompted students for a justification of their position or claim (indicated in italics).

191 So you are trying to think about why in this case shouldn't embryo selection go ahead? So what sort of things could you think of? *Why shouldn't it go ahead?*
192 S1: Religion.
193 S2: Yeah, they could be religious or some of their families could be religious.
194 […]
195 *But why, why are you just throwing up religion*? What is it about religion that disagrees with embryo selection?

(L1)

In line 195, Amy not only prompted students to provide a justification for their claim but also moved onto prompting students to develop an argument that would demonstrate how religion might be opposed to embryo selection (utterance 195). Overall, Amy addressed students with a request for stating why in their answers or with 'why' questions 97 times, an average of 24 instances in each argumentation lesson. Her use of 'why' would suggest that providing reasons and epistemic questioning was an aspect she focused on during argumentation instruction.

Another way Amy prompted students to provide justifications was through asking them to provide *reasons* for their beliefs. She often used the term 'reasons' whilst going around the student groups and she even had a whole-class discussion with students during Lesson

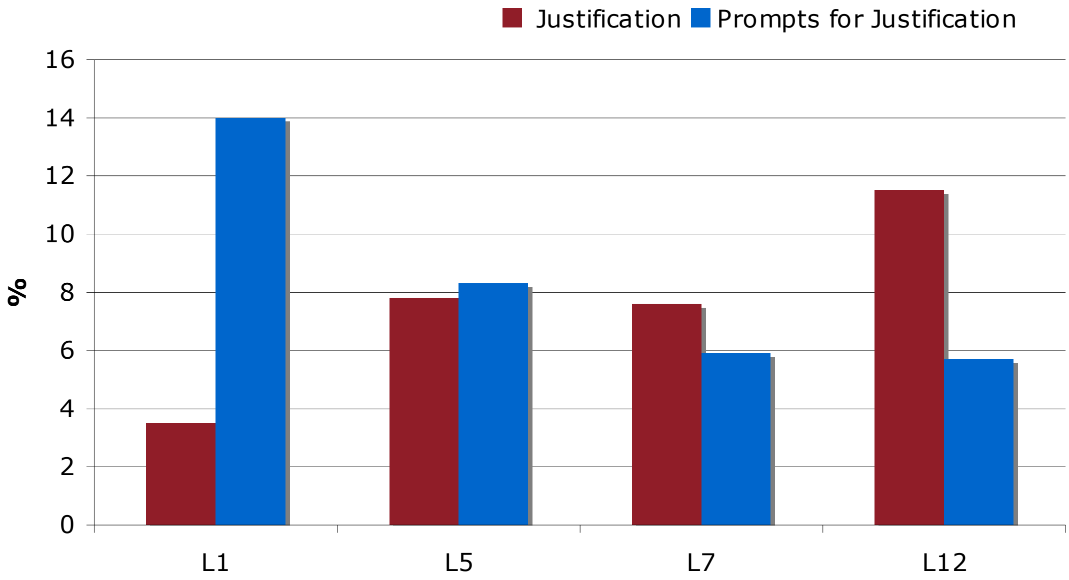
7 concerning the difference between providing 'evidence' or 'reasons' for a claim.

360 One point that I just want to bring out before we move on is that there were two columns in the middle. One column says evidence to suggest that the environment is recovering and one says *reasons* to suggest that the environment is recovering. Can anyone describe the difference between those two columns? So one says evidence to suggest the environment is recovering, one says reasons. What's the difference between those two columns? S5?
361 S5: Ehm, evidence is more like, it's more reliable,
362 […]
363 S6: Data.
364 The problem is in that reasons column you've got evidence, you've got data in that reasons column. S5 can you give me a reason […] why the environment might recover? What could be a reason of why the environment recovers?
365 S5: Less factories.
366 Yeah, less factories. So the reason why the environment is recovering is that say, there's less factories or there's less cars or we give off less air pollution. That's a reason of why it's recovering. What would be an example of evidence then? S7?
367 S7: The things that are actually happening.
368 Yeah so stuff that we can measure. I mean we can measure the thing that we put in the reason column but it's stuff, the effects of air pollution, we can see the effects being recovering. Is that what you, is that kind of what you were trying to say S7?
369 S7: Yeah.
370 […] So the evidence for recovering should be the ones that say that mosses and plants have returned, ok, dragonfly larvae have returned. The reason should be to do with the amount of pollution we've cut.

(L7)

The above discussion took place at the end of Lesson 7 as a whole-class discussion of the notion of 'reasons' and 'evidence' and their role within the arguments students were presenting. In prompting students to compare reasons and evidence and define them, she was being explicit about their function within their arguments and was a way of helping students understand how justification as a process can be achieved when students are constructing and defending their arguments. Figure 7.14 presents 'Justification' and 'Prompts for Justification' found in each of the four argumentation lessons. These are given as a percentage of the total number of epistemic operations identified in each lesson.

Figure 7.14: Types of justifications found in Amy's argumentation lessons



As shown in Figure 7.14, the use of the epistemic operation of 'Justification' seemed to increase from Lesson 1 to Lesson 12. At the same time, Amy appeared to use less 'Prompts for Justification' in her argumentation lessons. In Lesson 1 she provided much more 'Prompts for Justification' without engaging in this epistemic process herself, whereas this seemed to be reverted in Lesson 12, where she provided more instances of 'Justification' than 'Prompts for Justification'. A possible explanation of the decrease in her use of 'Prompts for Justification' could be the nature of the lessons in which these prompts are found. Namely, Lesson 1 focused on the nature of evidence and thus, prompting students to provide justifications through the use of evidence was a strong feature of this argumentation lesson. Lesson 12 emphasised evaluative processes, in which case the use of 'Prompts for Evaluation' would be greater than 'Prompts for Justification', as they were (9.3% were 'Prompts for Evaluation' [Figure 7.15] as opposed to 5.7% of 'Prompts for Justification' in Lesson 12). The increase of 'Justification' in her talk could be because she was influenced by her use of argumentation instruction in a positive way, which helped her develop this aspect of epistemic discourse in her own talk. However, as she only managed to teach four argumentation lessons throughout the school year, it remains to be seen if Amy was able to develop the justificatory aspect of knowledge production in her non-argumentation lessons and her everyday teaching practices. This issue will be further explored in Section 7.5.2 where her use of 'Justification' and 'Prompts for Justification' in her non-argumentation lessons are presented.

7.4.3 Evaluating Knowledge Claims: Providing and Prompting for 'Evaluation', 'Counter-Argument' and 'Compare and Contrast'

Evaluating knowledge claims was emphasised in Amy's argumentation lessons through the activities that she asked students to engage in, which often included evaluating each other's arguments and providing counter-arguments or evaluating evidence and classifying them according to which argument they supported. During these activities the most common epistemic operations employed in Amy's talk were 'Evaluation', 'Counter-Argument' and 'Compare and Contrast'.

7.4.3.1 'Evaluation' and Prompts for Evaluation'

'Evaluation' and 'Prompts for Evaluation' were two of the most common epistemic operations found in Amy's argumentation lessons (Tables 7.9 and 7.10). The nature of evaluative comments provided had a dual function. Firstly, she utilised evaluative remarks as part of an IRE pattern when talking to or with the students, similar to the way that James used IRE in Case study 1 (Chapter 6). In particular, 35 of the 57 coding references for 'Evaluation' could also be classified as IRE, only providing some kind of short feedback to the students such as 'Well done' in utterances 260 and 264 below from Lesson 5.

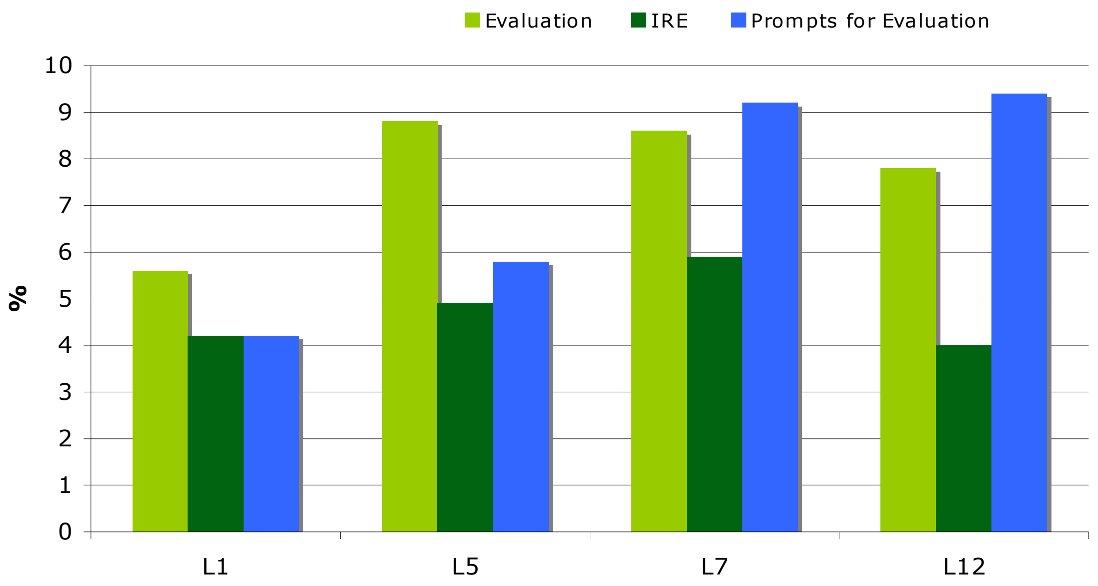
254 *What do we reckon?*
255 S: Volcanoes.
256 Why do we think that?
257 S: Because it has more evidence supporting it compared to the other one and there's like less against points and also because,
258 Can you remember what we call those against points?
259 S: Counter-arguments.
260 *Well done.*
261 S: And also because, what was I going to say? Volcanoes is more and an asteroid has more, there's more volcanoes in that time compared to how many,
262 So they're more frequent events, they are more likely to happen.
263 S: Yeah.
264 *Well done.* (L5)

The second and more valuable function of evaluative comments found in Amy's talk, was when 'Evaluation' served an epistemic function. This would be the case when examining whether one claim is better than another and providing criteria for making this comparison as she did in the following extract, where she had heard students' arguments and then provided an evaluative comment on the way that religion was presented in the students' arguments.

> 'So just one point that's come out of that which I could hear quite a lot of you banging this word "religion" around as a reason why people is against it. What you have to be careful with is if you are going to use religion as a viewpoint you have to explain why'
>
> (L1)

Moreover, instances where the teacher provided an evaluative comment and accompanied that with further evidence or used epistemic operations such as 'Generalisation', 'Justification' or 'Explanation' was also considered as an instance of 'Evaluation' with an epistemic function, as a judgment was provided and supported, to an extent. The function of the epistemic operations that followed Amy's evaluative comments to the students' answers or actions was to provide support or justify the judgment made. Figure 7.15 presents a summary of the evaluative comments identified in Amy's talk during argumentation lessons.

Figure 7.15: Evaluative comments provided by Amy in argumentation instruction



The use of ‘Prompts for Evaluation’ seemed to increase from the first argumentation lesson to the final one (Figure 7.15). As in the increase of ‘Prompts for Justification’ (Figure 7.14), the use of ‘Prompts for Evaluation’ seemed to be influenced by the nature of the lesson taught. The first argumentation lesson focused on constructing arguments for or against embryo selection, and thus instances of encouraging students to engage in an evaluative process were identified only after students had already constructed their arguments and they should then share their results and evaluate each other’s arguments. In Lessons 5 and 7 evaluative processes were utilised throughout, even though the focus of these lessons was on the use of evidence to support or reject an argument. Specifically, in Lesson 5, students were given two opposing theories for dinosaur extinction and various pieces of evidence, and had to match them to create an argument.

Accordingly, the main objective of Lesson 7 was to provide an answer to the questions ‘Was it fair to call Britain the “dirty man” of Europe?’ and ‘Is the acid rain crisis really over’, both of which require students to make a judgement and evaluate the evidence given to them. The same evaluative processes were required for Lesson 12 where students had to evaluate whether statements provided to them based on data from a graph (Appendix J). Therefore, Amy was able to include activities that enabled the students’ engagement with evaluation in all of her argument-based lessons. This action would suggest that Amy had an underlying understanding of the evaluative processes of science and of how these can be made explicit through the process of argumentation. What is more, she demonstrated an improved ability to prompt students to engage in this evaluative process, as shown by her use of ‘Prompts for Evaluation’ in Figure 7.15.

Overall, ‘Prompts for Evaluation’ was the main way through which the evaluative practices of science were represented in the science classroom, as students were prompted to engage in this process. Thus, they are thought to hold a greater epistemic load compared to the instances where the teacher herself attempted to provide an evaluative comment, as those were mostly of an IRE pattern. For instance, in utterance 254 (p.196, Lesson 5), Amy asked for the student’s opinion about which of the two theories the student thought was the best, which then led to a ‘Prompt for Justification’. In this way, all the students of this group, who were listening to the conversation, were able to share and establish some criteria and rules for evaluating arguments, such as ‘having more evidence' and 'less against points' in order to make a decision.

7.4.3.2 'Counter-Argument' and 'Prompts for Counter-Argument'

In her lessons, Amy made explicit references to counter-argument. She described the function of an argument as taking a position and being able to 'provide reasons for why you believe something' and then asked students to listen to the other pair in their groups and 'if they are coming up with something, can *you come up with a suggestion to why that's wrong [...] come back at them*' (L1). Thus, in Lesson 1 for example, she asked students to create arguments, that firstly, were not necessarily their own beliefs or opinions, a cognitively demanding task, and secondly, she encouraged her students to engage in counter-argument by considering how other students might contradict them so as to be ready to reply to any counter-evidence or positions presented to them.

Contrary to Amy's use of 'Prompts for Counter-Argument' which were present in all argumentation lessons observed, the epistemic operation of 'Counter-Argument' was present mainly in Lesson 5 (5/6 coding references) and only once in Lesson 1. This would suggest that, as in the case of 'Argument' and 'Prompts for Argument', Amy was more concerned with engaging students in counter-argument rather than presenting counter-arguments to the students. Amy encouraged students to provide counter-arguments by having students who were previously supporting opposing arguments to present to each other their point of view and support it, as was the case in Lesson 5.

329 So S1, what do you think?
330 S1: Honestly, I think it's the volcano. I'll give you my reasons why. Firstly, I believe that, because of two reasons. One is eruption, yeah, lava it can travel up to miles and kill, whereas gas, gas is giving out highly toxic gases are given out as well. And gas will make more damage than an eruption. Where an eruption it affects the same amount of area, where gas will travel more than an eruption if they could.
331 *Right, so how are you going to come back to that then?*
332 S2: Ehm, the asteroid hit both started, it killed a few people in the area,
333 Dinosaurs. People weren't around.
334 S2: Yeah, right, and that's actually, those volcanoes around there, so it blew those up, so eruptions.
335 So it triggered the volcano,
336 S2: Yeah it triggered them, and then like, volcanic gas got set up as well as stuff from the...

337 Asteroid.
338 S2: Asteroid, that's the word. And that extinctions were the food and the [inaudible]
339 *Would you agree with that?*
340 S1: Partly yeah.
341 So you could accept that an asteroid impact triggered volcanic eruptions you think?

(L5)

During this lesson, Amy asked students who supported the view that the volcano theory accounted for the extinction of dinosaurs to argue with students that believed that the volcano theory was not a good enough explanation of this phenomenon. In the example provided above, she initially asked S1 to state their argument before she prompted S2 to 'come back' to that (utterance 331). After the second student attempted to provide a counter-argument she also prompted the first student to evaluate the second student's response (utterance 339). In this way, she was advancing the epistemic discourse of her students by having them using evidence to support their views and also use evidence that would oppose the other student's view, a practice that is cognitively challenging, as students need to consider evidence both for and against and evaluate each other's positions.

7.4.3.3 'Compare & Contrast' and 'Prompts for Comparison'

'Compare & Contrast' was another way in which Amy engaged her students in evaluative processes, especially through combining it to the epistemic operation of 'Counter-Argument'. For example, in the next extract from Lesson 5, she compared one possible explanation of why the dinosaurs were extinct initially with evidence students had been given in order to show the mismatch between theory and evidence. This attempt to coordinate theory and evidence was then followed by the formation of a counter-argument to support the extinction of dinosaurs was the result of a super volcano rather than an asteroid collision.

> […] there's actually evidence that conflicts with that [the asteroid collision theory], so a bit like a counter-argument if you like. And it says that there are two problems with the asteroid collision. That we know that many dinosaurs and plants and animals had started to die out before the asteroid struck and we know that there have being other asteroid collisions that haven't caused any extinctions. So there is a bit of a problem with our theory there. […] it

> doesn’t quite fit, so other scientists have come up with another explanation. They think it’s a super volcano. So the earth was very-very active millions and millions of years ago and there were lots and lots of volcanoes and they think that possibly eruptions from these volcanoes could have caused the extinction of the dinosaurs’
>
> (L5)

The coordination of theory and evidence through comparing evidence and contrasting evidence to a theory involves an evaluative process of thinking where students are required not only to understand the content of the evidence but also to be able to make a judgment about how each piece of evidence relates or not to a claim/theory. Successful engagement in activities of coordination between theory and evidence requires a reasoning ability that students hold to a certain extent (Driver et al., 1996; Sandoval & Millwood, 2005) but that needs to also be addressed explicitly in the science classroom for students to acquire a deeper understanding of the nature and role of evidence and theories in science (Sandoval & Morrison, 2003). Through the argumentation lessons Amy taught and through the emphasis that her argument-based instruction placed on processes of evaluation and counter-argument, this explicit attention to the nature of evidence and its coordination with theories to explain a phenomenon was present, especially in Lesson 5 as mentioned above.

Comparing and contrasting information was also part of Amy’s classroom talk during Lessons 7 and 12, through the epistemic operation of ‘Prompts for Comparison’. During these lessons, Amy asked students to work in their groups or with other groups of students and compare their answers or arguments.

> ‘[…] you are going to compare answers. If you’ve got the same [answers], *did you do it for the same reasons*? If you’ve got differently, *why did you disagree*? What’s different about your answers?’
>
> (L12)

> ‘Can you find yourself another group and when you move to that new group I want you firstly to see if you've put your cards in the same place as they have but, secondly, share with each other your conclusions, OK? Did you come up with the same conclusion? *Have you used the same piece of evidence* to come to your conclusion or *have you used different pieces of evidence*?’
>
> (L7)

As can be seen in the two examples above, prompting students to compare results and answers was also complemented by a prompt for evidence or justification (shown in italics) to support the results that each group of students had, which engaged students in the process of evaluation of scientific knowledge claims.

On the whole, during the four argumentation lessons observed, argument construction took place during pair or group work activities where the students had to use evidence provided to them as to take a position on the issue discussed and justify it through this evidence. Amy seemed to use the epistemic operation of 'Generalisation' in her argumentation lessons as a way of establishing the knowledge already given or discussed with students in previous lessons and helping them create a ground on which to base their arguments. 'Generalisation' and 'Description', which are both considered as epistemic operations of a lower epistemic function, were extensively used in her own talk. However, when Amy was addressing students and encouraging them to talk, the epistemic function of her prompts was of a higher cognitive level. She focused specifically on promoting students in each group to develop their arguments and to provide justifications in order to make their arguments stronger. The way Amy initiated and sustained classroom talk during her argumentation lessons, shows that the initial practices or discursive actions with a lower epistemic function are present although these are moving towards increasingly more challenging epistemic operations, through her prompts, such as prompting for justifications and engaging in the processes or evaluation and counter-argument.

7.5 Epistemic Features of Amy's Classroom Talk During Non-Argumentation Instruction

In this section, the epistemic operations that Amy utilised whilst teaching non-argumentation lessons are presented and discussed for their function in the construction, justification, evaluation and communication of scientific knowledge. The results are presented in Tables 7.11 and 7.12. Table 7.11 presents the epistemic operations that Amy employed whilst talking and Table 7.12 includes the epistemic operations she attempted to engage her students in, whilst talking with them.

Table 7. 11: Epistemic operations performed by Amy in non-argumentation lessons

	Coding References (%)			
		Whole class	Group-work	Individual work
Provides Evidence	176 (19.1)	52	48	76
Evaluation	147 (16)	62	23	62
Justification	116 (12.6)	58	27	31
Description	58 (6.3)	38	8	12
Exemplification	39 (4.2)	15	11	13
Generalisation	26 (2.8)	13	7	6
Explanation	26 (2.8)	14	5	7
Analogies & Metaphors	16 (1.7)	5	5	6
Compare & Contrast	12 (1.3)	7	2	3
Argument	11 (1.2)	1	5	5
Definition	9 (1)	4	2	3
Modelling	4 (0.4)	4	0	0
Prediction	3 (0.3)	1	0	2
Counter-Argument	2 (0.2)	2	0	0

Table 7. 12: Epistemic operations promoted by Amy in non-argumentation lessons

	Coding References (%)			
		Whole class	Group work	Individual work
Prompts for Evidence	150 (16.3)	78	30	42
Prompts for Justification	27 (2.9)	9	8	10
Prompts for Evaluation	26 (2.8)	7	5	14
Prompts for Argument	15 (1.6)	3	6	6
Prompts for Description	15 (1.6)	7	4	4
Prompts for Definition	14 (1.5)	9	3	2
Prompts for Classification	10 (1)	0	0	10
Prompts for Prediction	10 (1)	4	5	1
Prompts for Comparison	6 (0.6)	2	2	2
Prompts for Counter-Argument	2 (0.2)	0	2	0

The two tables are organised firstly, by the number of coding references of each epistemic operation identified in the transcripts overall, and secondly, by the nature of the activities students and teacher were engaging in during the talk (whole class, group-work or individual). It is worth mentioning, that the theme 'Individual work' was created and applied during the coding process of these non-argumentation lessons, since in the ordinary science lessons observed, Amy often asked students to work individually on a task which she did not do during her argumentation lessons. The analysis and interpretation of the results included in Tables 7.11 and 7.12 are presented next.

7.5.1 Constructing Knowledge Claims: 'Provides Evidence' and 'Prompts for Evidence, Description and Exemplification'

The main epistemic operations Amy utilised to construct or reconstruct her students' knowledge and understanding of scientific concepts were 'Provides Evidence' and 'Prompts for Evidence', 'Description' and 'Prompts for Description' and finally, 'Exemplification'.

7.5.1.1 'Provides Evidence' and 'Prompts for Evidence'

The dominant discursive action found in the eight non-argumentation lessons Amy taught was providing factual information to the students or prompting students for some information or evidence. One reason for this strong preference to focus on facts and information is partly because two of the ordinary lessons observed (Lessons 9 and 10) were revision lessons for the students' upcoming exams. A great part of each of these two lessons was devoted to a whole-class quiz activity where the teacher was presenting students with questions ('Prompts for Evidence') and the students would then either write their answers on a sheet and evaluate each other's' responses at the end (Lesson 9) or would write their responses on a small white board and present to the teacher (Lesson 10), which case she would give the correct answer ('Provides Evidence') and evaluate students' responses ('Evaluation'). However, even when the two revision lessons are not accounted for in the analysis of the non-argumentation lessons, providing and prompting for evidence is still the strongest feature in Amy's classroom talk (Appendix J). Instances of providing and prompting students for information/evidence are provided below.

326 S1: Is our sun exploding?
327 […] Yeah, eventually when it runs out of fuel, when it runs out of hydrogen atoms to use, it will start to cool, and then it goes through the process of star birth, it's not quite big enough for a supernova. It will get bigger and then it will get very small again.

(L10)

In the above example from Lesson 10, Amy was providing evidence to a student as they working on a revision booklet for unit P1: The Earth in Universe. This pattern of student-teacher interaction was frequent throughout the eight lessons observed and aimed at answering students' questions and establishing their understanding of the issues discussed. A different way in which Amy used the epistemic operation of 'Provides Evidence' as part of her ordinary science teaching was as part of a combination of epistemic operations, whilst in whole-class, as in the extract from Lesson 2 provided next.

'That pair of girls [projected on the board] are in fact identical twins. And the thing about identical twins is that they are clones.	*Provides Evidence*
Because they have exactly the same genes as each other.	*Justification*
So clone is someone or something with identical genes to something else.	*Definition*
Does anyone know how identical twins are formed? How are identical twins formed?'	*Prompts for Evidence*

(L2)

At first, Amy provided information about the picture telling them that it was a par of identical twins, which can be considered as clones. She then went on to justify why identical twins are clones before she provided students with a general definition of a clone. She subsequently continued the conversation prompting students with questions about how identical twins are formed in an attempt to elicit students' prior knowledge on the subject.

7.5.1.2 'Description' and 'Prompts for Description'

'Description' was another epistemic operation present in all the ordinary lessons observed. As can be seen in Table 7.11, descriptive talk was mainly used in whole-class discussions, especially at the beginning of each lesson. During that time, Amy described to students the activities they would be engaging in during the current lesson or she was using ‘Description’ to refer to previous lessons and connect that to the current lesson, as was the case in Lesson 3.

> ‘the point of this lesson is to summarise what we’ve done over the last few lessons, […] talking about volcanoes, we’ve done a bit about talking about continents moving, we've done a bit about showing that the sea floor, the crust is actually moving apart. We’ve done quite a bit but what we need is try and bring that altogether and to make some sort of sense out of it. Now this diagram here is quite good, it’s a bit of an animation and it will show you some of the stuff we've being talking about’
>
> (L3)

Another way Amy used the epistemic operation of ‘Description’ was to help students realise what they had to do in some of the tasks they were involved, as in Lesson 6, where students had to go through a worksheet of questions on a set of data (Appendix J). When the students had difficulty understanding a question she would describe the experiment on which the worksheet was based as to help them understand what was asked from them. In this way, she avoided giving students a direct answer and instead challenged them into thinking about the experiment she had described to them and evaluating it. As a consequence, the epistemic operation of ‘Description’ had different levels of ‘epistemic load’ depending in its function within the talk taking place.

7.5.1.3 ‘Exemplification’

The use of the epistemic operation of ‘Exemplification’ was present often in the non-argumentation lessons taught by Amy. Providing students with examples of the concepts or situations discussed was a way for Amy to make her students see the application of those concepts as well as a way of making the connection between the scientific concepts and their everyday life application. For instance, in Lesson 2, she had introduced the concept of ‘asexual reproduction’, and used the example of a spider plant she had on her desk to talk about it.

> ‘Asexual reproduction involves one parent, no sex cells. So […] my spider plant it’s exactly the same, ok? No pollen, no seeds but yeah these little bits here are baby spider plants. OK? So from this one plant it's now growing baby

> spider plants, which will eventually drop off and can be planted to create a whole new plant that will look exactly like this' (L2)

In this case, the use of 'Exemplification' was to help students realise what asexual reproduction with one parent meant and to make that process explicit to the students. Another way in which 'Exemplification' was employed by Amy was to make information or concepts provided to the students more specific as in the case below, during group-work in Lesson 4 ('Exemplification' shown in italics).

> **336** S: Oh, so floods are because of rainfall? […] 'Cause I thought, I thought it could have been the wind that blows it...
> **337** It's often to do with rain fall, *so those floods we had recently in Cumbria, they were on the news-those had to do with heavy rain fall.*
> **338** S: Oh.
> **339** *And where you get lots of rivers joining together, and you've got heavy rainfall and all those rivers are full they often burst their banks'*
> (L4)

In replying to the student's comment on the possible causes of a flood, Amy provided two examples in order to support the claim that rainfalls can often be the cause of geo-hazards such as flooding. She first gave a specific example from the news of a catastrophic flood in the area of Cumbria and she also provided a more general example of how rainfall can influence rivers, which overflow and cause floods. In this way, she established with the student that rainfall was the possible cause of floods and utilised 'Exemplification' as a way of justifying why that was the case.

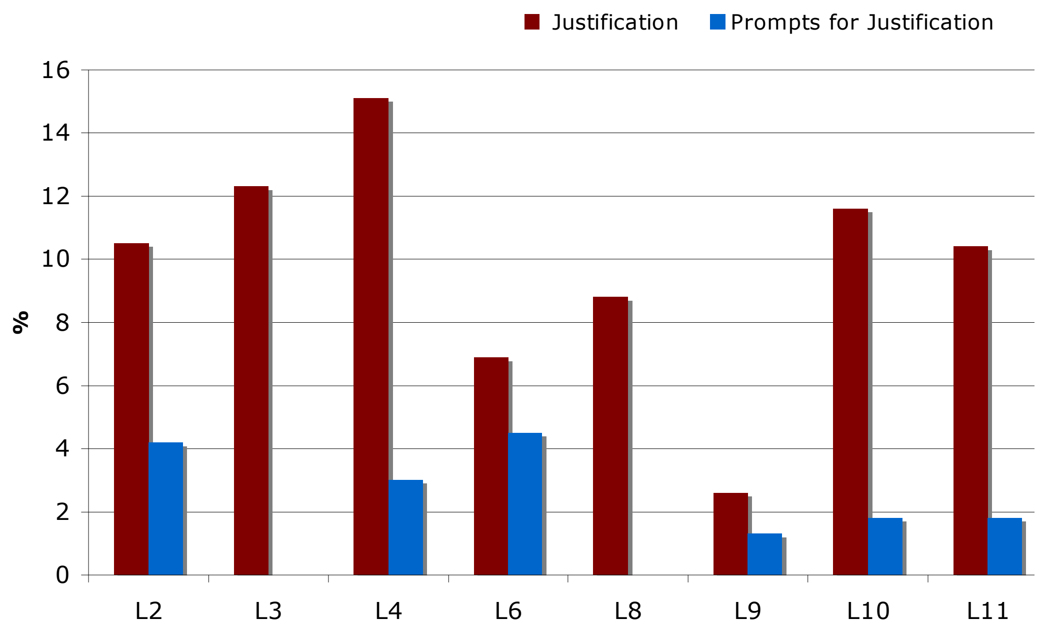
7.5.2 Justifying Knowledge Claims: 'Justification' , 'Prompts for Justification' and 'why'

The epistemic operation of 'Justification' and 'Prompts for Justification' were two of the most common features of Amy's talk during ordinary science teaching (Tables 7.11 and 7.12). The types of 'Justification' Amy utilised in her teaching as well as the ways in which she prompted students to provide justifications are further discussed next.

7.5.2.1 'Justification' and 'Prompts for Justification'

The epistemic operation of 'Justification' was found 116 times in the eight non-argumentation lessons observed. Of those, 73 references were categorised as a content-based justification, most of which were used during a whole class discussion. Procedural justifications were also present in Amy's classroom talk, but to a lesser extent. Figure 7.16 presents the percentage of justificatory comments made in each of the eight non-argumentation lessons observed.

Figure 7.16: 'Justification' and 'Prompts for Justification' in Amy's non-argumentation lessons



The use of 'Justification' across the eight lessons observed varied depending on the type and content of each lesson. In particular, the presence of justificatory comments was almost non-existent in Lesson 9 (one of the revision lessons observed), during which the teacher focused on epistemic operations such as 'Provides Evidence', 'Exemplification' and 'Prompts for Evidence' (11, 10 and 20 coding references accordingly, Appendix J). Moreover, especially in Lessons 4 and 8, where students had to work in groups in order to create a presentation, justificatory comments were mainly procedural in nature dealing with how students should approach working together and sharing the task rather than the topic on the topic of their presentations. Conversely, in Lesson 2 and 3, where scientific concepts and processes were discussed (i.e. unspecialised cells, cloning, plate tectonics, seafloor spreading) ‘Justification’ was mainly content-based.

‘Prompts for Justification’ was considerably less, even thought it was the second most used discursive action prompted in the non-argumentation lessons observed (Table 7.12). The teacher’s attempts to encourage students to provide a justification for their answers or views was mainly present in Lessons 2 and 6 (Figure 7.16). These prompts for justification were often put forward using the question ‘why’. An examination of Amy’s classroom talk showed that she utilised the word ‘why’ 37 times in her non-argumentation lessons. ‘Why’ references were used both as a prompt for justification (asking students why) and as part of an explanation or justification, such as ‘this is why it looks like a shooting start’ (L10). The extract that follows is an example of how Amy used the question ‘why’ to make students realise the importance of unspecialised cells for cloning, that took place in a group discussion during Lesson 2. In this case, Amy wanted to point out the function of unspecialised cells in organisms, and therefore compared cloning in humans and plants.

316 S1: I’m thinking this [inaudible]
317 Right. So *why* is it that we can’t produce clones of ourselves?
318 S1: Because we need science to do that.
319 Yeah, but *why* can’t we do it naturally? So plants…
320 S1: Because it’s got to be done chemically.
321 ...can produce clones. Yeah, but *why, why*? If we could just leave a plant,
322 S1: Because we’ve got two parents.
323 Right, so we have two parents. So *why* is it important that we have two parents?
324 S1: So we have different characteristics.
325 Yeah, you’re right, that is true, but *why* is it, that we can’t have one parent? What do you need to produce a clone?
326 S2: Two sex cells.
327 [No]. What do you need asexually? So asexual reproduction is basically producing a clone, producing another plant […] S1, *why* can plants reproduce asexually but we can’t? What have they got that we haven’t got? And it’s in there [book] […]
329 OK, so as we grow we have lots of different types of cells and as we grow our cells become specialised.
330 S1: They have specialised cells.
331 OK, *we* have specialised cells, OK? Things that can reproduce asexually keep unspecialised cells. So they can use the unspecialised cells to produce a clone of themselves.
332 S1: Oh, OK.

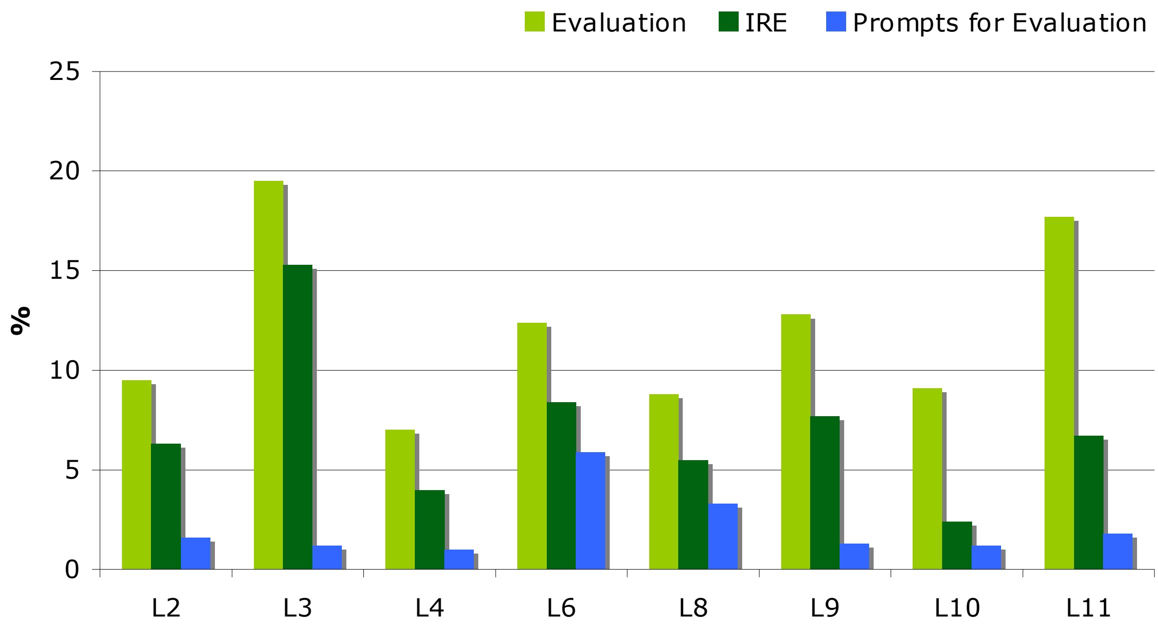
333 We haven't got lots of unspecialised cells so we can't produce clones of ourselves.

Amy insisted on asking students 'why' questions (utterances 317, 319, 321) to lead them towards the realisation that the main requirement for asexual reproduction is the presence of unspecialised cells. At first, students provided different reasons for why humans cannot produce clones naturally and she therefore continued to ask them 'why' comparing reproduction in plants and humans, so as to lead students to realise the role of unspecialised cells in asexual reproduction. This way of questioning students was valuable in helping them understand the concepts involved and was a way of developing the epistemic discourse taking place between her and the students. Yet, requesting for justifications and reasons took place only within the particular group of students, and a similar line of questioning was not present at the whole-class talk that followed the group-work activity, which supports the view that prompting students for justifications was not part of Amy's teaching practice during this lesson, or her other non-argumentation lessons.

7.5.3 Evaluating Knowledge Claims: 'Evaluation' and 'Prompts for Evaluation'

The epistemic process of evaluating scientific knowledge claims has been part of Amy's classroom talk during her ordinary science teaching through the epistemic operations of 'Evaluation' and 'Prompts for Evaluation'. As presented in Table 7.11, the epistemic operation of 'Evaluation' was a common discursive practice by Amy. In particular, 147 'Evaluation' instances were found in Amy's eight non-argumentation lessons, and from that, 84 were categorised as IRE. The thematic category of 'Evaluation' has being applied where the teacher provided feedback or responded to students' answers, without any further elaboration or explanation provided. So, for instance, a comment such as 'a few mixed answers; most of them are the same, it is (a). Well done. 4000 million years old' would be considered as IRE, which Amy made when students answered the question 'how old do scientists think the earth is'. Conversely, as in the case of argumentation lessons, a response where the evaluative comment is followed by epistemic operations such as 'Generalisation', 'Explanation', 'Description' or 'Provides Evidence' would be considered as epistemic, since the aim of the teacher was to use the students' responses to advance their understanding or test their knowledge of a concept. For instance, when she evaluated another response from students who had been asked to evaluate which of three statements were not correct about the sun (the sun's energy comes from the fusion of hydrogen atoms; the sun is a ball of fire; the sun is a source of heat and light), she then also prompted students for evidence to justify their answer saying 'Excellent it is B. *Why is the sun not on fire? Why is it not burning*' (L10). Figure 7.17 provides the evaluative comments identified in Amy's classroom talk, including the IRE instances and the 'Prompts for Evaluation'.

Figure 7.17: Evaluative comments identified in Amy's non-argumentation lessons



'Prompts for Evaluation' were considered instances where the teacher was asking students to make a decision or judgement on an issue. In fact, most coding references for 'Prompts for Evaluation' in a non-argumentation lesson came from Lesson 6 (Figure 7.17). An activity during this lesson, required from students to evaluate the process of an experiment and its results and determine possible errors with the equipment and the actions of the scientists that obtained the results under discussion (Appendix I). As many of the students were unsure of what they had to do for this activity, Amy was prompting them to think about what possibly went wrong, such as 'So what could, what about this [experiment] could mean that you get different results?' and '[…] but is that a problem with the equipment or is that a problem with the method and the skill of the researcher?' (L6). For instance, in the second example above, a student suggested that it was the force used to blow the bubbles, which accounted for the variation in the repetitions of the experiment. Then, Amy prompted him to make a judgment for whether than would be related to the equipment used or the skill of the researcher, engaging him in this way in a process of evaluation. Overall, the evaluative process of scientific practices were not a feature that Amy focused on during her non-argumentation lessons since she her use of 'Prompts for Evaluation' was limited throughout the school year (Figure 7.17).

On the whole, during non-argumentation instruction, Amy emphasised the construction of knowledge through epistemic operations such as providing and prompting for evidence/information, 'Exemplification' and 'Explanation'. These epistemic operations characterised the majority of her classroom talk during non-argumentation instruction. What is more, she made use of the epistemic operations of 'Evaluation' and 'Justification' although she did not attempt to engage her students in those processes as instances of 'Prompts for Evaluation' and 'Prompts for Justification' were considerably less. The similarities and differences between Amy's classroom talk during argumentation and non-argumentation lesson are discussed in detail in the following section.

7.6 Comparing Amy's Argumentation and Non-Argumentation Lessons

The four argumentation lessons taught were characterised by an emphasis on evaluative processes, which were operationalised through epistemic operations such as 'Evaluation', 'Counter-Argument', 'Compare & Contrast', and especially her prompts for students to engage in these actions (see Tables 7.9, 7.10 and Figure 7.15). In all of the four argumentation lessons Amy taught, opportunities for evaluating claims, evidence and processes were provided. Students were asked explicitly to consider views and provide counter-arguments or evaluate other students' arguments and opinions and state whether they agreed or disagreed with them, providing evidence to support their views. On the contrary, the main focus of Amy's classroom talk during the eight non-argumentation science lessons observed was on providing factual information and constructing or reinforcing students' knowledge of the issues discussed.

Figure 7.18: The epistemic operations identified in the ***4 argumentation lessons*** *taught by Amy throughout the school year*

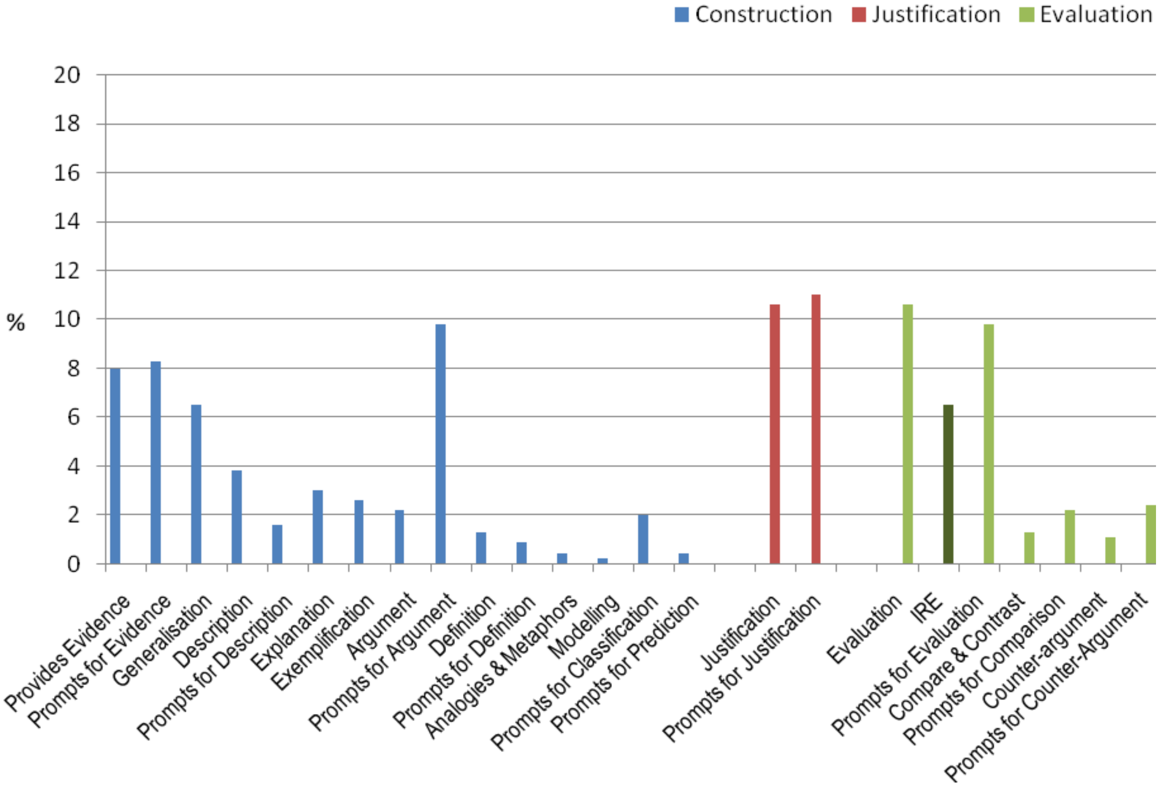
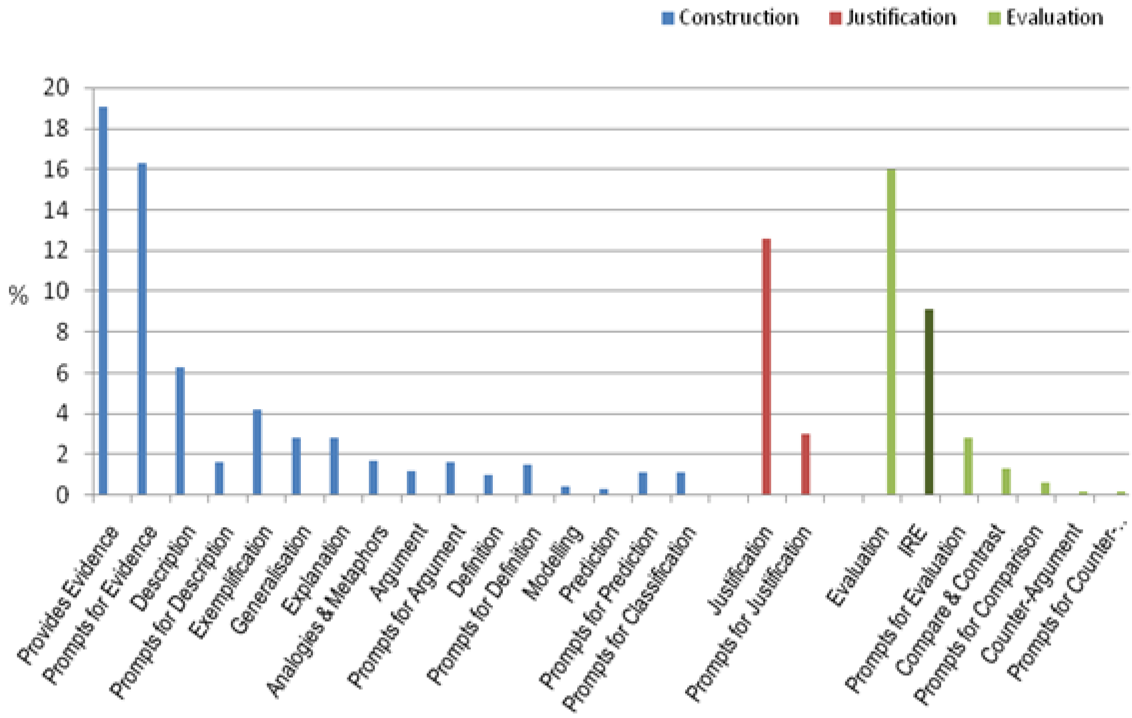
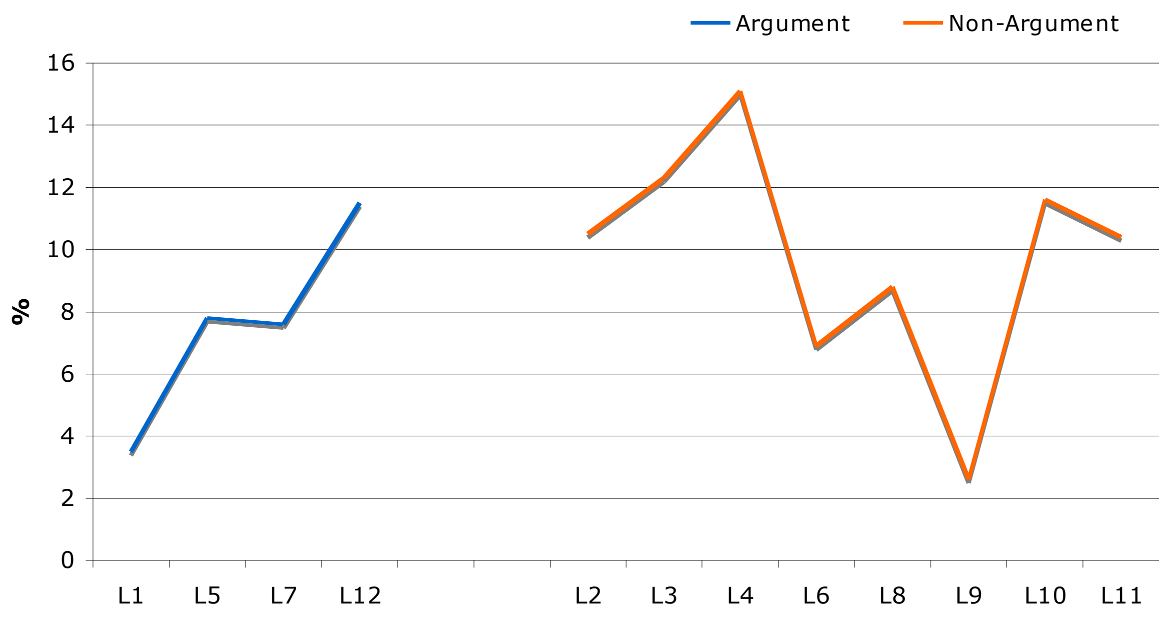


Figure 7.19: Epistemic operations identified in talk of the ***8 non-argumentation lessons*** *taught by Amy throughout the school year*



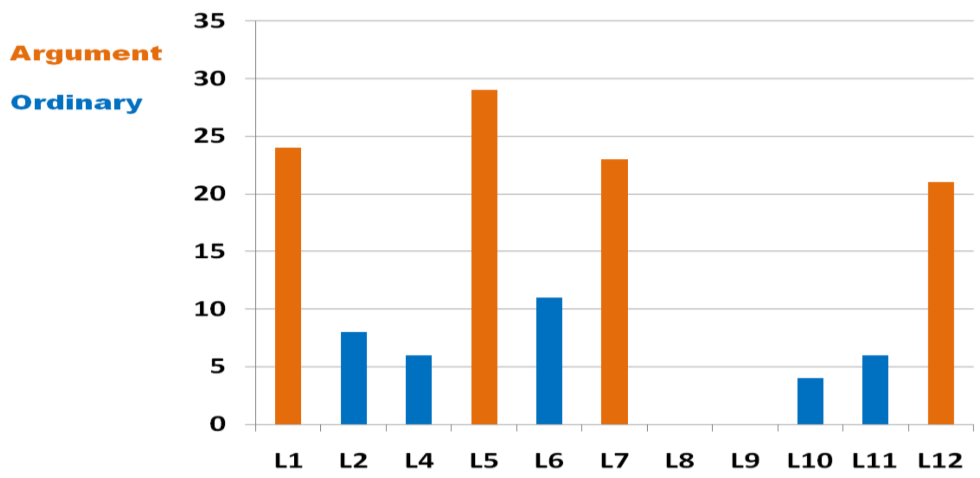
From Figure 7.18, it is evident that during argument-based instruction, Amy emphasised the justificatory aspect of science, through the use of the epistemic operations of ‘Justification’ and ‘Prompts for Justification’. Moreover, she provided opportunities for her students to engage in the epistemic practices of construction through ‘Prompts for Argument’ and ‘Prompts for Evidence’, and the practice of evaluation through ‘Prompts for Evaluation’. In non-argumentation instruction, there seemed to be a swift towards the epistemic process of constructing knowledge claims on the expense of evaluative processes, as was the case of the teacher in Case Study 1. In particular, more than a third of her classroom talk (35%) involved providing or prompting students for information and another 9% was providing evaluative comments through IRE interactions. This would suggest that the nature of the classroom talk during non-argumentation instruction was authoritative with the teacher emphasising declarative knowledge and facts. Nonetheless, in non-argumentation instruction, the presence of ‘Justification’ was similar to that of argumentation lessons. Figure 7.20 presents a comparison of the use of the epistemic operation of ‘Justification’ across the school year in argumentation and non-argumentation instruction.

Figure 7.20: Amy’s use of the epistemic operation of ‘Justification’ throughout the school year



It seems that during argumentation instruction, initially, Amy did not use ‘Justification’ much as part of her talk, but instead focused mostly on prompting students for justifications (Figure 7.14). What can be concluded from the justificatory aspect of her classroom talk is that as in the case of James, providing justifications was part of her classroom talk in both argumentation and non-argumentation instruction. However, the same cannot be said for the epistemic operation of ‘Prompts for Justification’, which as shown in Figure 7.19 took only 3% of the total of classroom talk analysed during the eight non-argumentation lessons. Furthermore, Figure 7.21 demonstrates the use of questions and prompts using the word ‘why’ employed by Amy across the school year. Using why questions is considered as a way to develop epistemic discourse in the science classroom as students are in this way asked to reconsider their views, provide evidence or evaluate the evidence used to support a claim. In Amy’s lessons, it is evident that why prompts were much greater during argument based-instruction compared to non-argumentation instruction.

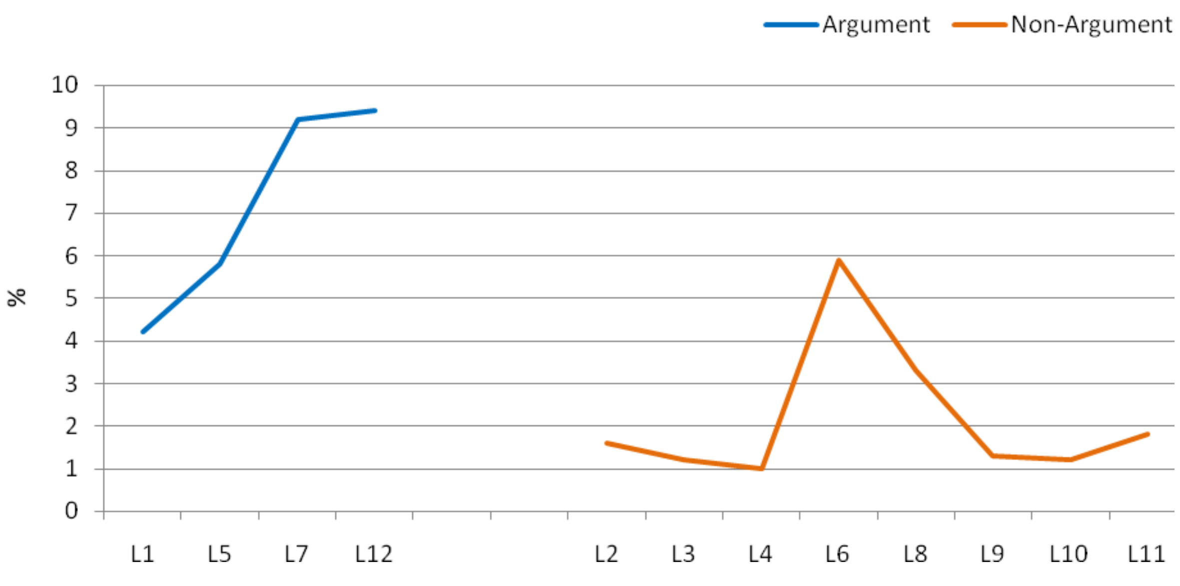
Figure 7.21: Using ‘why’ in Amy’s lessons throughout the school year



On the whole, it seemed that Amy was not able to make the epistemic operation of ‘Prompts for Justification’ part of her everyday practices as a result of her engagement with argument-based instruction, as demonstrated from Figures 7.19 and 7.21. As in Case Study 1, the use of epistemic operations, such as ‘Prompts for Justification’ seemed to be context-dependent (Section 7.4.2.2). Even though Amy managed to provide justificatory comments herself she nevertheless did not employ the epistemic operation of prompting students for justifications and asking them 'why' questions in her ordinary science teaching.

Another finding emerging from the comparison of Amy's argumentation and non-argumentation instruction presented in Figures 7.18 and 7.19 is her use of evaluative processes. In argument-based instruction, Amy utilised mainly 'Prompts for Evaluation', and, 'Prompts for Comparison' and 'Prompts for Counter-Argument', to a lesser extent. Conversely, during non-argumentation instruction there were only a few times in which Amy prompted students to engage in an evaluative activity, as described in Section 7.5.3 and presented in Figure 7.17. Figure 7.22 presents the use of 'Prompts for Evaluation' in the two types of lessons across the school year, providing further support to the view that the evaluative processes of science were not part of Amy's everyday teaching practices, in contrast to her argument-based instruction.

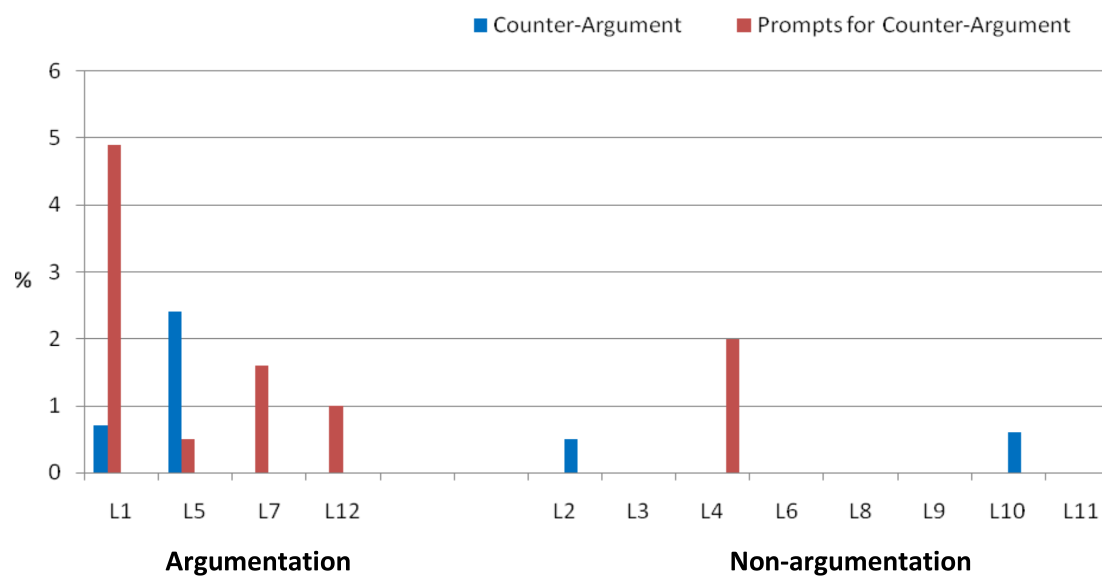
Figure 7.22: Use of 'Prompts for Evaluation' in argumentation and non-argumentation lessons



Amy used the epistemic operation of 'Prompts for Evaluation' more towards the end of the year, compared to her first argumentation lesson (Figure 7.22). As discussed in Section 7.4.3.1, this increase could be attributed to her planning of argumentation lessons and her understanding of the evaluative processes of science, which can be presented through the practice of argumentation. This view is also supported by her perception of argumentation as a process of making a decision on an issue, as shown through her lessons. For example, in Lesson 7, she explicitly stated to students that they would look at some evidence and effects of air pollution, and they would then be asked to make a decision on the issue. Thus, by presenting the task to the students in this way she set up the lesson to include an evaluative process.

What is more, she only engaged in the epistemic operation of 'Counter-Argument' and Prompts for 'Counter-Argument' twice each, throughout the eight ordinary lessons. This practice is in contrast to her efforts in argument-based instruction to either present students with counter-arguments or encourage them to engage in the process of counter-arguing, as shown in Figure 7.23.

Figure 7.23: 'Counter-Argument' and 'Prompts for Counter-Argument' in the two types of lessons taught my Amy across the school year.



As shown in Figure 7.23, the discursive practice of providing alternative viewpoints to students was almost non-existent in non-argumentation lessons, even though Amy was able to use the epistemic operations of 'Counter-Argument' and 'Prompts for Counter-Argument' in her argumentation lessons.

Finally, a conflict between Amy's own discursive actions and the way she encouraged her students to talk was identified. Namely, the epistemic operations that Amy engaged were not at the same epistemic level to the epistemic operations she prompted students to engage in whilst using argumentation to teach science. This was especially evident in the way she used the epistemic operations of ‘Argument’, ‘Counter-Argument’ and ‘Evaluation’ where the discursive actions performed whilst talking were less to the actions she prompted students to engage in. This mismatch is important for approaches that aim to promote and develop argumentation-based practices in science schools since teachers, such as Amy need to be given the opportunities to develop epistemic discourse themselves through their talk, in addition to learning how to promote their students’ engagement in this epistemic discourse.

On the whole, a comparison of Amy’s argumentation and non-argumentation lessons shows that she perceived the two types of teaching as distinct and did not successfully manage to incorporate some of the processes she emphasised during argumentation lessons into her everyday teaching practices. Amy viewed argumentation as a generic approach to science teaching instead of separate lessons during her second interview at the end of the year but her teaching practices as examined through her classroom talk did not mirror that belief in her non-argumentation lessons. Namely, Amy was able to promote epistemic discourse during her argumentation lessons through the prompts she used to engage students in talking and thinking processes. She was also able to plan her lessons in a way that promoted the epistemic processes of justification and evaluation, in addition to the construction of knowledge that was already part of her discursive practices (Figure 7.19). However, during her non-argumentation instruction Amy relied on IRE patterns of interaction heavily and was not able to incorporate in this practice, the epistemic discourse she successfully engaged with her students during the four argumentation lessons observed.

7.7 Summary

As presented in the previous sections, Amy was aware of both the dialogic and epistemic nature of argumentation and had a sophisticated understanding of NOS (interviews 1 and 2, Section 7.3). She also believed that using argumentation to teach science should not be seen as a distinct approach to science instruction but as ‘a vehicle’ for teaching science, helping students develop their thinking skills and their conceptual understanding, and at the same time present them with various facets of the nature of scientific knowledge and practice. Nevertheless, there was a conflict between her beliefs and views of argumentation and her practice in terms of the epistemic discourse that was present in her non-argumentation lessons. During the course of the year, Amy managed to teach successfully four argumentation lessons that had high levels of epistemic discourse. Yet, these lessons were end-of-unit lessons. Additionally, no influence on the non-argumentation lessons observed teaching was identified which concurs with her difficulty in finding ways of using argumentation with content-based lessons rather than socio-scientific issues, as expressed during her interviews. In fact, during an informal conversation, she expressed the view that she would continue to use argumentation activities in her lessons, even after the end of the project, but she would not organise an entire lesson based on argumentation. Rather, she mentioned that she would use 'some' argument-based activities in her various lessons.

CHAPTER 8

STUDENTS' CONCEPTIONS OF THEORIES AND EVIDENCE IN SCIENCE AND THE NATURE OF THEIR CLASSROOM TALK

8.1. INTRODUCTION

As part of the two case studies developed for this thesis one group of four students from each class was also observed and interviewed. The focus placed on these two groups of students aimed at providing answers to research questions 3 and 4, which were:

> **RQ3.** What are students' understanding of the nature and role of theories and evidence in science, over the course of a school year?
>
> **RQ4.** What are the epistemic features of students' classroom talk during argumentation activities over the course of a school year?

In order to answer RQ3, student interviews were conducted at the beginning and end of the school year using the same interview schedule (Appendix B1). The student interviews focused on students' personal and formal epistemologies of the nature and role of theories and evidence in science. Formal epistemologies are defined by Sandoval (2005) as the views that students hold about the nature of scientific knowledge and practice, as opposed to their practical epistemologies, which are the ways the students choose to use evidence and reason while doing their own investigations. As a result, during the interviews, students were asked to give their views on what theories, facts and evidence are and how these concepts relate to each other in order to form a picture of their formal epistemologies. Moreover, students were asked to describe what kinds of activities scientists undertake and how certain they can be about topics such as dinosaurs, the Earth's shape and how Earth was created, and finally, what science is. Their practical epistemologies were examined through different tasks during the interviews, such as providing students with competing theories and asking them to consider which is the best, why, and then, comment on pieces of evidence that supported or rejected the theories (Driver et al., 1996; Osborne, Erduran & Simon, 2004a). Another task included students considering the nature of evidence through asking them to order pieces of evidence from the most convincing to the least convincing justifying their actions. To answer RQ4, the four students selected were also observed as they worked in their pairs or groups, during the argumentation and non-argumentation lessons that their teachers were observed teaching. The students' talk was transcribed and analysed for the epistemic operations that the students engaged in whilst talking in their groups.

This chapter focuses on the four Year 9 students followed as part of the first case study presented in Chapter 6. The selection of students was made by the teacher who was asked to select a representative sample of students from the particular Year 9 group he was teaching, in terms of attainment, interest in science and gender. Students should also be able to work together, as they would be observed collaborating during argumentation lessons. As a result, James selected four students, two boys and two girls (see Appendix K for the teacher's assessment of these students). The results from the students' interviews are discussed in Sections 8.2 and 8.3, both for their formal and personal epistemologies, and, how these might have changed across time. This information is presented in order to provide a detailed description of the four students selected. As this is a qualitative, exploratory case study, this detailed description of students' views about science contributes towards exploring the different aspects of science learning and teaching that were taking place in the classroom observed. The full list of themes identified in the students' interviews is presented in Appendix B2. Section 8.4 includes the presentation of the students' views of the practice of argumentation. Finally, Section 8.5 provides the analysis of the students' verbal interactions during the six argumentation lessons James taught with a focus on the epistemic operations that students utilised when talking together.

8.2 Students' Conceptions of Facts, Theories and Evidence and their Relation For the Practice of Science

This section presents the results of the students' formal epistemologies on the nature and role of theories, facts and evidence for the practice of science. Students' ideas of the links between theories, facts and evidence are also reported.

8.2.1 Students' Conceptions of 'Theories'

The main conception of theories that students provided through the first set of interviews was that of a tentative idea or opinion. According to these four students, theories could be true but one could not be sure unless the theory was tested or proven to be true. Furthermore, experimentation and testing were mentioned by students as the ways in which theories can move from 'opinions' to 'facts'. For instance, when asked whether the climate change statement they were asked to comment on (Appendix B1), could be a fact, S3 replied:

> S3: No, because it's not being properly tested or, like it's not being experimented to check.
> I: OK. What do you mean 'experimented'?
> S3: They haven't found out yet, they are still thinking, they are planning to find out.
>
> (S3-1)[11]

The theme 'theories are tested through experimentation' was identified in three of the four student interviews (S1, S3 and S4), both in the first and second interview sets. In addition, during the second interview two of the four students (S1 and S3) provided an understanding of the word 'theory' as something more than just an idea or opinion, considering the predictive nature of theories. In this sense, students were able to provide a more complex conception of theories during the second set of interviews, since they were able to add the predictive function of theories to their existing repertoire of the notion of theory. However, none of the students, either during their first or second interview,

[11]The first number denotes which student the quote came from and the second number indicates whether it was from the first or second set of interviews.

expressed an understanding of theories as explanatory mechanisms. As mentioned in Chapter 4, scientific theories provide explanations of the physical world (Duschl, 1990; Harré, 1984) and thus, students mentioning the explanatory nature of theories for the practice of science, either implicitly or explicitly, would constitute a more informed understanding of the notion of scientific theories. One explanation for the students' inability to make the link between theories in science and explanations is the way that the word 'theory' was used or better, not used, during their science lessons. James did not mention at any point during the lessons observed the word 'theory' or made any links of the concept of 'theory' or 'scientific theories' to explanations. As a consequence, students tended to use the word 'theory' based on its everyday use and meaning and not as a 'scientific theory'. The students' notion of 'theory' as a tentative idea was consistent even when students talked about scientists, by expressing the view that scientists use theories as ideas in their work since 'they make up theories and test them […] to see if they are true or not' (S1-1).

During the second set of interviews, improvement on the concept of theories was identified particularly in S2's comments. This student, during her first interview, described theories as an 'estimate' or something that 'is more than a guess but not a fact because it's not proven' (S2-1). The view of theories expressed in her second interview was more complex since she was in a position to also consider how theories can be backed up by evidence saying that 'theories are made up but can be supported by evidence' (S2-2). She expressed the same view of 'evidence backing up theories' when prompted to consider how theories are used in science, as shown below (in italics).

> I: Do we use theories in science?
> S2: [Yes].
> I: How?
> S2: […] some scientists say that everybody's believing the carbon dioxide thing how it's changing the Earth's atmosphere; it's all because of scientists they obviously think of a theory and then *they use the evidence to back it up*'
> (S2-2)

A comparison of the student's comments in her first and second interviews shows that this student's thinking about theories and facts moved from the straightforward idea that 'proven theories become facts' towards an understanding which included the consideration of evidence and the process through which an idea maybe supported even if it is 'not completely true'.

8.2.2 Students' Conceptions of 'Facts'

The main conception of 'facts' identified in the four students' first set of interviews was that of 'facts' as true and definite knowledge that had been proven and established by scientists. Moreover, students expressed the view that testing and experimentation was the way to prove that a proposition is factual and 'a hundred percent' true. When students were asked to comment on how facts are used within science they replied talking about facts within school science rather than science in general. In particular, students mentioned how they would use facts for learning or 'research on it and see how it was proven' (S1-1) and 'to teach us stuff really, like to know stuff about the world and what happens' (S2-1). In addition, 3 of the 4 students mentioned that 'we learn facts' during the first interview whereas only one student (S2) commented on facts as something that the students learnt at school, during the second set of interviews. Moreover, during the first interview, S3 stated that facts could be expanded on or adapted to consider new information, but not changed, as they are a certain piece of knowledge. In this sense, it could be argued that this student recognised the cumulative nature of scientific knowledge but not the tentativeness of scientific knowledge, which might be rejected or proven wrong in light of new evidence and developments within the scientific enterprise.

Comparisons of the students' accounts of facts between the two sets of interviews, showed that the main difference was the view of facts as evidence to support or 'back up' a theory. The theme 'facts are used as evidence' was more evident during the second set of interviews. In particular, two of the students that did not mention the use of facts as evidence in scientific investigations during the first interview (S1 and S2) were able to consider the role of facts as evidence during their second interview. For instance, S2 initially mentioned that a fact is 'something that it's been proven, like the world is not flat, that's been proven' (S2-1) but when further prompted she was not able to explain how she knew that. However, during the second interview, she was not only able to provide an example of a fact but she was also able to provide some justification for that fact, as shown below.

S2: [An example of a fact is] we have lungs.
I: OK. Why is that a fact?
S2: Because… we wouldn't be breathing if we didn't have them and […] they can take pictures of your insides and stuff like that so that's how we know as well'

(S2-2)

In addition, when asked if, and how, facts are used in science during her first interview, she replied:

'to teach us stuff really, like to know stuff about the world and what happens because not everybody can find, like me for example I can't find this out at the moment because I just can't ['is climate change a theory or a fact']. No one can really find out if it's definitely true or not. So everybody is just going on [with] what the scientists are saying'

(S2-1)

In the example above, this student placed great emphasis on the authority and expertise of scientists for making the decision on climate change, instead of considering critically the statement that was given for discussion. Nonetheless, during her second interview, when asked to consider the same climate change statement she expressed the view that climate change was a fact and was able to provide reasons to support her viewpoint. She also demonstrated an understanding of factual knowledge as warranted through evidence.

'S2: …because we've being using carbon dioxide like over the years, like it's getting worse and worse and worse; because of the cars and stuff. Whereas before we didn't have cars and stuff and like, the climate was like normal but now we [are] getting more and more of the climate changing.
I: So you think it's a fact?
S2: Hm.
I: And why isn't it a theory?
S2: Because if it was a theory then they wouldn't have evidence to back it but whereas they [scientists] do have evidence to back it up'

(S2-2)

'Facts are used as evidence' was a theme identified in her first interview where she mentioned that facts were used to 'back-up theories' in order to prove a theory correct. However, in her second interview, although she again mentioned that facts are used to back up theories, she did not mention the notion of proving a theory and turning it into a fact. Interestingly, throughout her second interview, the word 'proof' or 'proving' was not mentioned at all, demonstrating in this way a more evaluative stance towards the way that facts are used in scientific investigations.

Finally, it is worth mentioning that students did not completely change their conceptions of the notion of facts. Rather, students added to their existing ideas of facts, creating a more complex understanding of what a fact is and how it can be used within the practice of science, whilst maintaining that a fact is something absolute and true. For instance, S1 initially defined a fact as ‘something that it’s proven and it’s not wrong’, a view that was maintained during the second round of interviews, where she said that ‘a fact is something that has being proven and it’s true and […] it cannot be proven wrong because there is evidence that is true’. In her second interview, she was able to consider that facts become more certain as evidence is supporting or verifying them, instead of the more absolutist perspective that ‘facts are not wrong’.

Overall, the concept of facts as something proven and true was dominant in the students’ interviews and was the main way through which they conceptualised the use of facts within scientific investigations. The main change identified was the emergence of the consideration of facts as evidence in scientific investigations instead of the end-result of scientific practices. The students’ notion of ‘evidence’ is further explored in the next section.

8.2.3 Students’ Conceptions of ‘Evidence’

Students’ understanding of the nature and use of evidence in the practice of science was also investigated as part of the interviews. Initially, all students considered the role of evidence as ‘backing up’ ideas or a theory with the purpose of that support being to ‘turn a theory into a fact’. For instance, S1 mentioned that ‘the evidence proves something and makes a theory into a fact’ (S1-1). Conversely, during her second interview, S1 defined evidence as ‘the results from your experiment’ or ‘clues that show you if you are right or not’ demonstrating an ability to better define the concept of ‘evidence’. Moreover, through both her interviews, S1 commented on the role of evidence as that of transforming a theory into a fact. Yet, during the second interview she was also able to consider how evidence could be used to indicate the extent to which a claim could be true. Specifically, she stated that 'evidence' can 'turn a theory into a fact' and when she was prompted to elaborate further on that answer she mentioned that 'if there is a theory and you do an experiment then you get evidence whether it's true or false and if it's true, and you've got enough evidence, then it turns into a fact' (S1-2). In this respect, S1 seems to have moved from an understanding of using evidence to prove something right or wrong, into qualifying her statement with the requirement of 'having enough evidence' for deciding whether a theory could be a fact. This response indicates that the particular student moved towards a more evaluativist perspective on the creation and establishment of scientific knowledge through explicitly considering the role of evidence within scientific practices during her second interview.

Another way in which students presented 'evidence' was that of confirming reasons for believing a statement or claim, as S3 mentioned in the example below.

> S3: It's like something to back up a statement, so […], you have to have the evidence to, like if you believe something you can't just say I believe it, you have to have a reason to believe it.
> I: And the evidence?
> S3: It's the reason.
>
> (S3-1)

S3 initially described evidence as 'backing up theories', which can then be made into facts and when prompted he gave the answer above, which is considered as an informed view of the role of evidence for scientific practices. During his second interview, S3 was also able to consider how evidence could be obtained through experimentation, an aspect that was not mentioned in his first interview.

> 'I: What do you think evidence is?
> S3: It's something to back up your theory or a fact.
> I: So it could back up any of the two?
> S3: Yeah.
> I: Why?
> S3: Because […] evidence it's like say you tested it out and this is what happened and it supports the answer because of whatever happened'
>
> (S3-2)

Additionally, during the ‘The Earth is round’ task, S3 described that the statement ‘scientists have seen pictures and videos from satellites’ as ‘accurate evidence’ which is ‘not a random piece of evidence but it has been researched very thoroughly’ (S3-1). When asked about whether it is important to select the theory with the most evidence in support of it he replied positively explaining that it is important to do so:

> ‘Because […] it’s not about the quantity of the theory, like about of the evidence, it’s about the quality of it. So like, if you get 100 [pieces of evidence] that are a little, not detailed ones, just like statements, but if you get 5 really detailed and well-explained ones then [it is better]’
>
> (S3-1)

Another of the students was able to put into consideration the amount of evidence a theory needs to be proven. S4 mentioned how ‘once you’ve got a certain amount of evidence your theory is true; otherwise your evidence is wrong or your theory is wrong’. In this statement, he presented an understanding of the possibility of making mistakes when dealing with evidence and how one needs to be prepared to revise their views or theories in light of new or disconfirming evidence. During the second interview, S4 considered ‘evidence’ as ‘things that help you prove that something is wrong or right’ and explicated further that ‘if you are arguing against somebody then to prove them wrong you could use evidence and facts to prove that you are right’ (S4-2). Comparing the views that this student expressed during his first and second interviews, it could be argued that he had developed an understanding of the role of evidence as used in support of an argument or a claim, although at the same time, he seemed to rely heavily on the notion of proof, demonstrating an overall absolutist perspective on the creation of scientific knowledge moving between the two extremes of ‘right or wrong’ and ‘true or false’. Additionally, it seemed that for S1 and S2, their understanding of the notion of evidence seemed to improve from the first to the second interview and their answers were more elaborate compared to the first interviews. S3, who demonstrated an informed understanding of the role of evidence in science initially, seemed to maintain these views during his interviews.

8.2.4 Making Links Between Theories, Facts and Evidence

During both interviews, students were asked to consider any possible links between the concepts of theories, facts and evidence as well as to discuss which they viewed as more important for the practice of science. As mentioned previously, the main link that students considered between the concepts of theories, facts and evidence was the transformation of a theory into a fact through a process of ‘proving’ or ‘experimenting. During the first interview all students mentioned that ‘proven theories become facts’ when asked to consider any possible links between theories and facts. For instance, during her first interview, S1 stated that transforming a theory into a fact was important ‘so people believe it, because not all people will have the same theory but if you turn it into a fact you can make them believe that it is true’.

The belief that proven theories become facts led three of the students (S1, S3 and S4) express the view that theories and facts are equally important for science as you cannot have the one without the other. For instance one student stated that ‘facts are used as evidence and without a theory you can’t have a fact’ (S3-1). Considering theories and facts as equally important for the practice of science was thought as a sophisticated response as students were able to consider the role of both theories and facts in science, and did not consider facts as the most important, even when they understood theories as nothing more than tentative ideas or educated guesses. The only student that thought that facts are more important during the first and second interview was S2, although S4 also considered facts as more important than theories during his second interview.

Additionally, even in the cases where students maintained their views on the links between theories, facts and evidence from the first to the second set of interviews, there were differences in the reasoning that students provided that could be an effect of their engagement with argumentation activities. For example, S2 at first stated that facts, overall, are more important than theories as they are proven and not just an opinion. During the second interview she maintained the view that facts are more important, but provided further reasoning to support her view stating that they are more ‘believable’ since a theory is made up and although it might have some evidence for it you would ‘obviously believe more a fact than a theory’ (S2-2). This way of reasoning is more elaborate than her initial response since she was also able to consider the role of evidence in the evaluation process. Yet, as she maintained the view of theories as 'estimates that are not proven', her conclusion of facts as more important was consistent with her views of facts and theories during her interviews.

Finally, the belief that 'facts create theories' was found in the first and second interviews of students S2 and S4. This belief is somewhat more sophisticated than the simplified view of theories that are proven true to become facts, as students were able to suggest that facts lead to the creation of theories rather than facts simply being the outcome of scientific investigations. Namely, students were able to consider the role of facts as not only evidence to support a particular theory but also as information that can be used to create an idea or theory. This view also implied an understanding of the scientific knowledge as manufactured by the scientific enterprise as opposed to the 'realist' or 'correspondence view' of knowledge that students of this age are found to hold (Carey et al., 1989; Sandoval & Morrison, 2003).

8.2.5 Students' Views of Science and Scientists

At the end of the interview, students were asked to consider whether the issues discussed during the interview and the tasks they undertook had any similarities or differences to the work of scientists. This aimed at eliciting students' views of scientists and their work. Often during the interview students would mention scientists and their work spontaneously and at other times they would refer to school science, in which case they were also prompted to consider whether scientists would do something similar or not. The main theme from the students' discussions of what scientists do was related to experimentation and testing. This was an aspect that the students mentioned as a difference to the activities they went through as part of the second part of the interview, since in the tasks they were asked to engage, they considered different evidence statements but did not undertake a practical test to obtain information. Other actions mentioned during the first set of interviews was that scientists would use 'much more evidence' in their investigations than during the interview (S3-1) and that they might 'get information from other scientists' (S2-1) implying that scientists might work together. S2 also pointed out that scientists were not always right and that they might have made mistakes since ‘everybody makes mistakes’.

During the second set of interviews, students maintained the view that ‘scientists make tests and they experiment with stuff’ (S3-2) but they were able to further elaborate on their answers presenting a more evaluative perspective on the processes in which scientists participate. For instance, S3 mentioned how ‘scientists find theories and experiment with them to decide which one works the most’ (S3-2) instead of ‘using evidence to see which theory is correct’ (S3-1), which he stated during his first interview. Another common theme present was ‘Scientists use theories, which they prove to make facts’, which students utilised in their attempt to link the issues discussed during the interview with scientists’ work. From the first to the second interview, there seemed to be a shift to the way that students talked about scientists’ work in terms of their use of theories, facts and evidence. For example, S2 initially mentioned how scientists try to see if the evidence is true or false whereas during her second interview she stated that scientists think of a theory and then use the evidence to back it up and they do experiments and tests to back up the theories. In this respect, the students’ tendency to mention ‘evidence’ more during the second interview and considering its role in scientific investigations was also part of the way that students thought and described scientists’ work.

In addition to prompting students to discuss what they thought that scientists do, they were asked to provide their own definition of science. Their full responses of the question ‘what is science’, during the first and second set of interviews, are presented in Table 8.13. During the first set of interviews, S1 and S4 were able to consider how science attempts to explain the natural world by describing how and what the world is made up of (S1) and how it works (S4), whereas S3 utilised experimentation as a way to describe science (Table 8.13).

Table 8.13: The four students' views of science

	Interview 1	Interview 2
S1	'Science is [...] about our world and how is made up and […] how everything is made up and what is made up of'. 'We learn [science because] we learn a lot of things about nature and like what happens how was it made why was it made'	[I think science is about] theories and facts basically making theories into facts and making theories out of facts.
S2	[Science is] basically everything, like you use science in everything really and when you get older, when I will be an adult is going to help a lot […] it could help with the food you are eating, it could help with activities you do outside school, like help you learn what exactly you are doing to your body and stuff like that. So it can help with everyday life as well. […] Scientists say for example not to put water in plugs, sockets like don't put them together because it will give you an electric shock or it would do something, so that would help as well, like just everyday stuff that you can use science to help, say what happens or whatever.	'Science is like something I'm learning at the moment but it revolves around me because like […] It's like everyday you are doing something that involves science kind of thing, but at the moment, it's something 'I'm learning and then I use some of that outside of school […] Like for example say with the light and heavy that theory one, like....it might be like dropping something in the water and then you think will it float or will it sink and then […] you use science to help you think…
S3	'Science is about experimenting and finding out new things all the time […] if one thing does this, would it mean that another thing would do that…'	Science is 'finding new ways of how things work and which is the best solution to stuff'
S4	Science is 'about the world and how it works, and, how everything in it was created and I suppose it's a bit like religion but not exactly […] because […] some religions are about how things were created, how things work, stuff like that, which is what some of science is like'	Science is 'the way things are […] it's about the things around you, why everything, I think it's a bit like philosophy in that sense because it proves, well it explains why everything is there and what everything is doing, why it's floating why it's sinking why [inaudible], why…

During the second set of interviews, the response provided by S4 was more elaborate as he was able to explicitly comment on the explanatory and descriptive nature of scientific practices. Change was also identified in the responses that S3 provided. In particular, S3 moved from an understanding of science as an experimental process of cumulating factual information to an exploration of ‘how things work and which is the best solution for stuff’ (S3-2). This response by S3 presents the explanatory purpose of scientific practices and also includes an implicitly stated understanding of evaluative processes of the scientific practices, which could be the result of the student’s engagement with argumentation during his science learning. As a result, students were able to conceptualise to an extent, the explanatory nature of scientific practices, even if they did not do that through their understanding of theories.

Overall, students seemed to improve their formal epistemologies of the notion of facts by being able to consider and comment explicitly on the role of evidence in scientific investigations and the creation of scientific knowledge. Their views of theories through the everyday use of the word did not allow them to consider the explanatory nature of theories in science. Yet, students were able to conceptualise, either explicitly or implicitly, the function of the overall practice of science as aiming to explain natural phenomena, as shown in Table 8.13, when asked explicitly. The students’ practical epistemologies and the ways in which they use evidence to reason about knowledge claims are presented in the following sections.

8.3. Students’ Practical Epistemologies: Coordinating Theory and Evidence

Students’ practical epistemologies were investigated through various tasks, which required students to coordinate theory and evidence. Specifically, in Task 1 (How we see things) and Task 2 (Floating and Sinking) students were given a set of competing theories and were asked to select the one they thought was the best, providing justifications for their answer. Then, students were either presented with evidence statements, which they had to evaluate and decide whether they supported, rejected, or were irrelevant to their theory (Task 1) or they were asked to make predictions based on their theory (Task 2).

The third task presented to students requested them to form an argument to convince other students that the Earth is round and not flat. Then, students were presented with five evidence statements that they had to evaluate and order from the most convincing piece of evidence to the least convincing piece of evidence providing justification for their decisions. The results of these tasks are presented and discussed below.

8.3.1. Students' Justifications to Theory Choice and Use of Evidence

8.3.1.1 'How we see things'

For the first task students were asked to consider where light comes from. In both interviews, all four students selected Theory 2 as the best theory and were in a position to provide some justification for their decision. The different ways in which students attempted to justify their decisions of theory choice during the two sets of interviews are presented in Table 8.14.

Table 8.14: Students' justifications of theory choice and use of evidence in the two interviews for 'How we see things'

	Interview 1 (coding references)	**Interview 2** (coding references)
Explain Evidence	4[12] (11)	4 (11)
Providing Evidence	3 (11)	4 (8)
Inappropriate use of evidence	2 (5)	1 (1)
Justifications other than evidence	1 (1)	--
Familiarity with Phenomenon	2 (5)	2 (2)
No Explanation	1 (1)	1 (1)

'Providing Evidence' was applied when students gave evidential support for their theory selection, such as:

> 'I think theory 2 is the best […] because if there was light rays from our eyes then we [would] probably see at night and there wouldn't be like light bulbs

[12] Numbers indicate the sources (how many students) in which the particular categories were identified.

> and everything; nobody would have invented that because we could just see with our eyes'
>
> (S1-1)

Seeing at night and the need to invent light bulbs is used by S1 as evidence that rejected the theory stating that light comes from humans and not from a light source. However, when S1 was asked to provide a justification that would support Theory 2 she did not provide any evidence as a justification but used her familiarity with the phenomenon of light and how we see, stating that Theory 2 'it's being proven, like we also know that light travels in straight lines so like it reflects off things and into our eyes so we can see'. 'Familiarity with the phenomenon' was also used as a way of justifying theory selection by S3, as shown below.

175 S3: I think Theory 2.
176 I: Why?
177 S3: Because if it bounces off the object it's the light bouncing off an object and then coming into our eyes so it's not like, it didn't come from, the light source doesn't come from our eyes, it comes from a light source.
178 I: OK. How do you know that there is no light coming out of your eyes?
179 S3: Because...I don't know why actually.
180 I: This one [Theory 1] says there's light coming out of your eyes and this one [Theory 2] says that there is light from somewhere else coming to your eyes.
181 S3: Yeah. The light bouncing off the object.
182 I: OK. Can you think of a reason that would reject Theory 1? That would show that Theory 1 is not correct?
183 S3: I don't think it, because like even if the light did come from your eyes and it bounced off an object the light source from your eyes will reflect somewhere else so it won't come straight back.

(S3-1)

When S3 was asked to justify his selection of Theory 2 he restated the theory in his attempt to provide a justification without using any examples or evidence that would support his theory (utterance 177). Then, he was asked to provide reasons for Theory 1 not being the best, which students tended to find easier to explain, but again even though he was able to model the process of light travelling, he was not able to successfully coordinate theory and evidence (utterance 183). During the second interview, he again used his familiarity with the phenomenon of light and seeing to explain his theory selection, but when asked to show how theory 1 could be wrong he was also in a position to provide evidence against Theory 1, such as ‘you wouldn’t need light bulbs or the sun’ (utterance 116 below).

112 S3: I think theory 2 because light reflects off things and then it comes into our eyes and our eyes don’t produce light so it can’t reflect and then bounce back. So it has to be the rays bounce on to...reflect objects and then come into our eyes.

113 I: So why isn’t theory 1?

114 S3: Because our eyes don’t produce light.

115 I: How do you know that? […] Think something that would show it is wrong.

116 S3: Like if your eyes produce light then you wouldn't need light bulbs or the sun or something like that to produce light.

(S3-2)

Similarly to S3, S1 also went from using her familiarity with how we see things for explaining her theory selection to using evidence to support why theory 1 is not the best of the two. Finally, S2 and S4 were able to use evidence to justify their theory selection in both the first and second set of interviews. After students selected the theory they thought was the best out of the two provided, they were presented with three evidence statements and they were asked to consider whether the evidence supported, rejected or did not influence their theory (Appendix B1). Overall, the students were able to explain the evidence statements given based on their theory. Successful coordination of theory and evidence was considered when students were able to consider how Statement A was not a conclusive piece of evidence as it could support both theories, Statement B could be qualified to show that we can see things during the night *if* there is a source of light; otherwise it supported Theory 1, and finally, Statement C supported Theory 2.

The results of students’ responses to these statements are summarised in Table 8.15. As can be seen from Table 8.15, S1 and S3 gave similar responses to statements A and C in their first and second interviews, with improvement noticed in their responses to these two statements.

Table 8.15: Students' responses in the 'How we see things' task

		Statement A	Statement B	Statement C
S1	Int1	Supports Theory 2 – familiarity with phenomenon	Explains how it can both support and reject Theory 2	Supports Theory 2 – explains why (because of the sun that is a light source)
	Int2	Irrelevant- does not affect theory 2, it talks about where light comes from	Explains how it can both support and reject Theory 2	Supports Theory 2-explains why and explains why not Theory 1
S2	Int1	Irrelevant- does not affect theory 2	Supports-uses evidence to show there is light from sources during the night	No Explanation
	Int2	Irrelevant – does not affect theory 2	Explains why it rejects theory 2 and why it supports theory 1	No Explanation
S3	Int1	Familiarity with phenomenon	Explains how it can both support and reject Theory 2	Supports Theory 2 – explains why
	Int2	Supports Theory 2 – explains why	Explains how it can both support and reject Theory 2	Supports Theory 2 – explains why and explains why not Theory 1
S4	Int1	Inappropriate use of evidence	Explains how it can both support and reject Theory 2	Supports Theory 2 – explains why
	Int2	Irrelevant-it talks about how light travels and not where it comes from	Explains how it can both support and reject Theory 2	Supports Theory 2 – explains why

For example, both students (S1, S3) were able to not only explain how Statement C supported Theory 2 during their second interview but they were also able to explain why it could not support Theory 1, as shown in the extracts below.

> [Statement C] supports theory 2 […] because if it's supporting Theory 1 then we wouldn't wear sunglasses because Theory 1 says that our eyes let out light and sunglasses are worn to protect our eyes from like really bright light like UV rays and like that. And you can only get that sort of light from other sources so that's why we wear sunglasses'
>
> (S1-2)

> I think it [Statement C] supports it [Theory 2] because if we, if light comes through our eyes and we wear sunglasses it would just bounce back straight through [our eyes] […] but if light comes through it like goes through the dark [lenses] it absorbs most of the light and then it goes through [the lenses to our eyes]'
>
> (S3-2)

Providing reasons to show why a Theory 1 was not correct was considered as an advanced thinking ability, since students were giving further support to their views that Theory 2 was correct. This thinking skill is an important aspect of students' ability to coordinate theories and evidence at the K-12 level as recent recommendations (NRC, 2011) stress the importance of students not only being able to acknowledge why a knowledge claim is correct but also why a competing claim is wrong. The ability to know why a knowledge claim is wrong strengthens the students' belief and conceptual understanding of the correct answer. Improvement to the reasoning that students provided was also identified in the responses of S1, S3 and S4 to Statement A (Light travels in straight lines), who went from restating the theory and using their familiarity with how we see things to explain the statement in the first interview, to being able to explain how light travels in straight lines did not affect Theory 2 in any way (S1 and S4). S3's response that statement A supported Theory 2 was also considered as an improvement to his initial response because he was now able to coordinate the theory and the statement coherently, even though he did not recognise that Statement A could also support Theory 1.

8.3.1.2 'Floating and Sinking'

The second task on coordination of theory and evidence was 'Floating and Sinking'. During this first interview, S1, S3 and S4 selected Theory 2 as the best out of the three theories to explain the phenomenon. In addition, all students were able to provide both direct and indirect evidence in support of their theory selection such as:

> 'I think theory 2 is the best […] because air particles are lighter and there is less of them than there are water particles, liquid particles, and so they would float on top of them, and if there is a cork, it's not totally all jammed up there is little holes in it which air is in and that's why it floats'
>
> (S1-1)

The only student that selected Theory 1 as the best was S2, who justified her selection based on her familiarity with sinking and floating but without providing any examples that would support her answer.

> [I think Theory 1 is] kind of true because I have had heavy stuff that actually float and obviously most light stuff floats, but some light stuff sinks because it goes underneath the water because the water kind of goes on top of it and goes underneath and the water pulls it down. But some heavy stuff does float'
>
> (S2-1)

During the second interview however, she was able to identify conflict in all three theories and demonstrated an improved ability to provide evidence for Theory 3 that she eventually selected as the best. Table 8.16 presents the ways in which they attempted to explain the predictions they were asked to make based on their theories and how many students provided each response.

Table 8.16: Students' justifications to theory selection during the two interviews for 'Floating and Sinking'

	Interview 1 (coding references)	**Interview 2** (coding references)
Explain Evidence	4 (19)	4 (16)
Providing Evidence	3 (14)	4 (10)
Inappropriate use of evidence	1 (2)	--
Justifications other than evidence	1 (2)	--
Familiarity with Phenomenon	3 (5)	--
Use of Several Theories	4 (7)	2 (2)

As in the first task, all four students were able to either explain the evidence they were presented with or provide their own pieces of evidence to justify their decisions for Sinking and Floating, both in the first and second round of interviews (Table 8.16). The aspect that students seemed to do better during the second set of interviews for this task, was the decrease of ways to justify their views that were not evidence-based. As can be seen in Table 8.16, 'Familiarity with Phenomenon', 'Inappropriate use of evidence' and 'Justifications other than Evidence' were not found at all in the students' discussions of

Sinking and Floating. Moreover, the students' use of several theories to explain a prediction instead of using the theory they had selected as the best also decreased with only S1 and S4 utilising this way of reasoning once in each of their second-round interviews.

An important feature of the interview schedule, particularly within Task 2, was the prompt to consider disconfirming evidence and attempt to provide a solution to possible problematic issues that might arise from that. As a consequence, none of the three theories provided to students about sinking and floating was the scientifically accepted explanation. After students selected a theory, they were asked to make predictions based on their selected theories and consider how each prediction supported or rejected their theory. Both confirming and disconfirming evidence were provided to each student and Table 8.17 presents the number of students that recognised conflict and the different ways in which students responded to the conflicting evidence, in both sets of interviews.

Table 8.17: Students' responses to conflicting evidence in the two interviews for 'Sinking and Floating'

	Interview 1	**Interview 2**
Recognize conflict	4	4
Accommodate Evidence	3 (S1, S3, S4)	3 (S1, S3, S4)
Change Theory	1 (S3)	--
Maintain Theory	2 (S1, S4)	2 (S1, S4)
Qualify Theory	2 (S2, S4)	1 (S3)
Reject All Theories and/or Create New Theory	1 (S4)	1 (S2)

Students in both sets of interviews, were able to recognise when the evidence presented to them were conflicting to the theory they had selected. As shown in Table 8.17, S1, S3 and S4 chose to accommodate the evidence presented to them in order to make them fit their theory, in both sets of interviews, although when prompted they could recognise the conflict between their predictions and the theory they thought was the best. For example, S3, who had selected Theory 2 as the best during the first set of interviews, stated that wood floats as 'there are little bubbles that contain air[inside the wood]' and also that candles, which he predicted would sink, eventually float as they 'hold air bubbles' (S3-1). Even though this student chose to accommodate the evidence presented to him instead of rejecting the theory straight away, he stated that his opinion was that candles contain air bubbles and 'if it [candle] does contain air bubbles then it does support it [Theory 2] but if it doesn't [contain air bubbles], then it doesn't support it [the theory]'. This statement shows that S3 was able to recognise conflict between the theory and anomalous data, but it was his knowledge of the issue discussed that led him to interpret the evidence as not conflicting to his theory of choice. During the second set of interviews, S3 chose to qualify his theory adding to it, instead of changing from one theory to another, as he did during his first interview.

Another way of handling anomalous data was to reject all the theories presented to the students in light of evidence and to attempt to construct a new theory/explanation for sinking and floating. This was successfully done by S2 during her second interview, who as mentioned earlier, she was able recognise conflict with all three theories, a realisation that led to her attempting to create a new theory. As mentioned in Chapter 4, Chinn and Brewer (1993) have identified seven ways in which students might react to anomalous data (ignoring, rejecting, excluding, postponing thinking about them, reinterpreting, changing only peripheral parts or conditions of their theory, and finally, theory change). According to Chinn and Brewer (1993) the most sophisticated response to conflict is the attempt to create a new theory that would account for all evidence; a choice that only one of the students made in each of the two rounds of interviewing (S4 in the first interview, S2 in the second interview). Yet, this does not necessarily suggest that students, who chose to maintain their theory or attempt to qualify it in order to account for all the evidence, are epistemologically weaker. In fact, such reasoning has been observed amongst scientists by Dunbar (1995), who found that scientists working in different laboratory settings often followed the same route of holding onto any inconsistent evidence and attempted to explain them rather than discarding them as errors. What is more, it seemed that the students' knowledge on the subject affected their beliefs and decisions in dealing with anomalous data. For instance, S4 who demonstrated an understanding of sinking and floating and was able to talk about density during his interviews, was also able to provide many examples that supported Theory 2 during the second interview, which made his belief in Theory 2 strong enough to resist any conflicting evidence presented to him earlier. The strength and quality of evidence and the ways in which students evaluated different pieces of evidence was explored through

Task 3, which required students to construct an argument and convince younger students that the Earth is round and not flat. The results from Task 3 are presented next.

8.3.2 Evaluating Evidence: 'The Earth is Round' Activity

The results of Task 3 showed that all students were able to provide an argument against the claim 'the Earth is flat'. During the first interview, all four students were able to provide direct evidence to reject that claim, such as 'if it was flat then if you were on a boat you'd took off the end. And, as I said before we've got the satellites so […] that would be able to show if it's flat or round' (S2-1) and 'if you go to some places like mountains […] you can't actually see a sort of flat, you see it goes slightly rounded' (S1-1). When students were further prompted to think of other evidence they were also able to provide indirect or inferential evidence such as 'you could tell them about how the core of the Earth, like it wouldn't be there if the Earth was flat' and 'because then the reflection of the sun onto the Earth, it would make day and night all weird and the seasons would all be wrong' (S3-1). During the second interview, students S1 and S2 demonstrated some improvement to the quality of the evidence they presented with the former mentioning how day and night would be different and the latter providing more pieces of evidence to support her argument, although she was not able to make any inferences from evidence to support her argument. S4 was able to provide evidence from both direct experience and through inferential thinking whereas S3 only mentioned evidence based on direct experience ('people have been to space and seen it […] and they have actually taken pictures and video evidence') during his second interview.

The five pieces of evidence that students were presented varied in their quality and the authority on which they were based on. Direct, perceptual evidence included Statement D (they have seen pictures and videos from satellites) whereas evidence based on inferential thinking was Statement A (because sailors can travel around the Earth with their ships and will never fall from the edge of the Earth) and Statement C (because the Moon and other planets are round). Statement B (it is in our science textbook, so it must be true) and Statement E (the scientists that went to space told everyone that's the way it is) aimed to address students' understanding of the authority and source of knowledge. Statements D, A and E were the statements described as the most convincing by students in both the first and second round of interviews. In fact, seeing pictures and satellites was the piece of evidence considered as the most convincing for all students during the first set of interviews. During the second set of interviews, S1 and S2 used Statement A as the most convincing since ‘it has happened’ (S1-2). The students placed statements C and B at the end of their continuum from the most to the least convincing piece of evidence and justified their answers usually by qualifying the statements as did S2, who mentioned that scientists saying that the Earth is round would be a good piece of evidence if it was supported by evidence such as a camera. She also maintained that:

> ‘just saying so they [scientists] could’ve kind of exaggerated and such but I suppose if different scientists at different times and they didn’t know each other and they all said the exact same thing then you could sort of tell it’s kind of true’ (S2-1)

In this way, S2 took into account social aspects of the scientific practice such as scientists ‘exaggerating’ and needing agreement for their knowledge claims to be accepted and validated by the scientific community. Moreover, students demonstrated an understanding of the tentativeness of scientific knowledge, especially when commenting on Statement B, which referred to textbooks. In particular, S1 placed Statement B at the end of her list during her second interview, stating that facts could change and thus, using the content of textbooks might not be the best way to support an argument. A similar view was expressed by S4 during his first interview, who placed Statement B as the least convincing piece of evidence since:

> ‘some textbooks might be right at something and some textbooks might be wrong. And the person who writes the textbooks have an opinion so someone who might not agree with something might write about something in one textbook and the one that does agree could write a different thing about the same subject’ (S4-1)

Overall, students prioritised direct perceptual evidence to inferential or indirect evidence in both sets of interviews. Their reasons for doing so however, seemed to be more elaborated in some cases, as with S4 when justifying why Statement C (because the Moon and other planets are round) was not a convincing piece of evidence. He went from stating that ‘not all planets have to be the same’ (S4-1) to maintaining that Statement C ‘just gives you an idea that the Earth would probably be round too’ although it would not be better than A because 'you could have 5 animals that are red and then you said this animal probably be red but it might not be' (S4-2).

8.4 STUDENTS' VIEWS OF ARGUMENTATION

The final part of the interview schedule addressed the students' views on the process of argumentation. As the students were participating in argumentation lessons, their views and understanding of what is the process of argumentation were addressed through prompting students to talk about any argumentation lessons they were taught recently and then, make the connection with what scientists do. Students' ideas of the process of argumentation during the first and second interviews are presented in Table 8.18 based on the responses or comments they made on argumentation. Students presented argument as a 'debate' (S3-1), as an attempt to prove your viewpoint (S1-1, S4-1) or 'make it stronger' (S2-1).

During the first set of interviews, students also mentioned counter-argument when prompted to talk about argumentation. This could be because the lesson they were asked to comment on was Lesson 6, which emphasised the construction of counter-arguments.

Table 8.18: Students' views on the process of argumentation as a scientific process and/or as a teaching approach

	Interview 1	**Interview 2**
S1	'People have different opinions so like they argue and then like, and in the argument once you've prove that their opinion is right, yeah... [Scientists use arguments] if two scientists have two different opinions then they argue which one is better and they use facts and theories to prove it.	[Argumentation] helps, it's good because like you can prove your point and you can come to a conclusion which might be between the both [viewpoints] and like make stuff better with it.
S2	I think he [the teacher] is trying to get us to argue our point across, about our theories and what we think. So like help make it stronger the point because if someone disagrees with it you've got to give more evidence or whatever to make sure the point is more stronger. […] Like for example you might have done experiments about it so you might use the experiments as a point to show that it's [my viewpoint] true.	[[When arguing] you have to get your theory and then you have to back it up with all the evidence, like you have to argue your way […] say you have […] a theory, and […] if you are against it then you get all the evidence that would make it not true and use all that to argue. I think it is [important for scientists to argue] because then they would think of all the reasons why it wouldn't be true whereas and all of the other people would think it is true and they'd use their arguments to back it up as well.
S3	'It's like, one person has a statement and you have to try and disagree with that, and try to find like what you think and its like a debate'	[With argumentation] there are ways to support something and there are ways to like go against something, [and that is important] cause you need like things to go for it and things to go like against it to find more, to adapt the answer and conclusions.
S4	[In Lesson 6] we were using some theories and some facts […] to argue against the other people, prove them wrong. [Argumentation is] like groups of people trying to prove that their theories are right or their way of doing something is right'	'if you are trying to prove, if you are arguing against somebody then to prove them wrong you could use evidence and facts to prove that you are right'

For instance, S2 mentioned that when disagreement exists, one needs to make their argument stronger by giving more evidence and show that their viewpoint is true. In a similar way, S3 mentioned that 'one person has a statement and you have to try and disagree with that' whereas S4 considered counter-arguing as an attempt to 'prove them wrong'. During the second round of interviews, students gave a more comprehensive description of argumentation as a process, with S4 mentioning how one could use facts or evidence to prove their point, something he did not mention during his first interview. Moreover, S2 mentioned that:

> 'you have to get your theory and then you have to back it up with all the evidence, like you have to argue your way […] say you have […] a theory, and […] if you are against it then you get all the evidence that would make it not true and use all that to argue.

In this way, she was able to comment on both arguing for and against a viewpoint, something that S3 was also able to do, as shown below.

> 'There are ways to support something and there are ways to like go against something, [and that is important] cause you need like things to go for it and things to go like against it to find more, to adapt the answer and conclusions'
> (S3-2)

In this case, S3 was not only able to consider arguing both for and against a viewpoint, but also how this process would influence the final conclusion, which could be 'adapted' to fit both sides. A similar, more evaluativist, position to the use of argument was provided by S1 who, although she still mentioned that argument assists towards proving a point, also maintained that the conclusion reached 'might be between the both [viewpoints] and make stuff better with it' (S1-2).

8.5 STUDENTS' TALK DURING ARGUMENTATION INSTRUCTION

The student observations aimed at answering the fourth research question of this thesis, which focused on identifying the epistemic features of students' classroom talk. Through the student observations, the nature of their talk could be examined, as well as the ways in which they managed to engage, or not, in the process of argumentation. For that reason, this section presents the analysis of the students' talk only during argumentation instruction. What is more, an examination of the talk of these four students as they talked together to construct their arguments and develop their understanding of the issues discussed, offers another way of investigating the students' understanding of the nature and role of evidence in science and their practical epistemologies for the concept of evidence, as students attempted to use evidence to convince each other and engage in argumentative talk. The discussions observed include the talk of the four students interviewed but also of other students that were sharing the same work-table. The thematic coding and analysis of the student talk was based on a framework of epistemic operations or discursive acts similar to those presented in Chapters 6 and 7. The epistemic operations identified in the students' talk as a result of this coding process are presented in Table 8.19. Moreover, Table 8.20 presents the instances that every epistemic operation was used in each of the six argumentation lessons.

Table 8.19: The epistemic operations found in the students' talk during argumentation instruction in Case Study 1

	Coding references (%)
Provides Information/Evidence	105 (17.7)
Proposing position	44 (7.4)
Requests Evidence-Information	36 (6)
Takes position	33 (5.6)
Description	31 (5.2)
Argument	18 (3)
Exemplification	5 (0.8)
Prediction-Guess	4 (0.7)
Generalisation	13 (2.2)
Definition	11 (1.9)
Analogy	10 (1.7)
Requests explanation	10 (1.7)
Explanation	7 (1.2)
Provides justification	84 (14.2)
Requests Justification	26 (4.4)
Evaluation	73 (12.3)
Requests Evaluation	15 (2.5)
Counter-position	51 (8.6)
Compare & Contrast	6 (1)

Table 8.20: Students' epistemic operations in each of the 6 argumentation lessons observed in Case Study 1

	L3	L4	L5	L6	L10	L13
Analogy	3	2	0	3	0	2
Argument	1	7	2	8	0	0
Compare &Contrast	3	0	0	0	3	0
Counter-Position	11	19	2	16	1	2
Definition	0	0	0	0	6	5
Description	1	3	2	9	8	8
Evaluation	9	29	12	11	3	9
Exemplification	0	0	0	4	0	1
Explanation	0	2	0	0	2	3
Generalisation	2	3	0	4	3	1
Prediction/Guess	0	2	0	0	2	0
Proposes Position	7	11	9	9	6	2
Provides Information/Evidence	9	29	13	16	15	23
Provides Justification	8	36	7	20	5	8
Requests Evaluation	0	12	1	1	0	1
Requests Information/Evidence	4	12	5	3	6	6
Requests Explanation	1	0	2	0	7	0
Requests Justification	0	12	6	5	3	0
Takes Position	15	8	4	3	2	1

The analysis and interpretation of the results presented in Tables 8.19 and 8.20 were organised based on the epistemic practices of constructing, justifying and evaluating knowledge claims, as was done for the teacher talk in Chapter 6.

8.5.1 Students' Attempts to *Construct* Knowledge Claims

As can be seen in Table 8.19, the most common epistemic operation students utilised when talking in their groups or with their teacher was providing information to each other about the activities they should engage in, the instructions they should follow or, about the topic they were discussing. 'Providing Information/Evidence' was a common discursive action that was present in all six argumentation lessons observed (Table 8.20). For instance, during Lesson 5, students were asked to describe a graph with two lines representing carbon dioxide and oxygen (Appendix G). To do that, their teacher wrote on the board the words ‘describe, explain, justify, argue’ (Figure 6.5), which S3 in the next extract attempted to use to form an argument identifying the two lines on the graph. In that process the student provided evidence to support his argument (shown in italics).

> S3: [reads from the board] Describe, explain, justify and argue. So I think that that one’s oxygen because it says that it will, *the plants release oxygen in, during the daylight hours from around 6 o’clock to 10 o’clock,* the daylight hours when it starts to rise, and then, *it absorbs the carbon dioxide, in daylight hours so it [the line] drops…*because it says around the plant not in the plant
>
> (L5)

‘Providing Information/Evidence’ was also found to be used when the teacher was at the students’ group either because students asked for help or because he was checking the students’ progress. For example, during Lesson 4 students were given a worksheet with statements they should evaluate as ‘true or false’ and then in a different column provide reasons to support their decisions (Appendix G). During that lesson, the teacher did a demonstration where he pushed a trolley and asked students to consider the forces acting on it when it started moving, as it started slowing down, and when it stopped moving. In the next extract, the teacher talked to the group and attempted to help students understand how even when an object starts to slow down it still has forces acting on it.

1. James: Just before it stopped, which direction was the net force acting on?
2. *S4: Forward.*
3. *S6: There’s nothing, you didn’t touch it.*
4. James: There is no force?
5. S6: There’s not.
6. James: So why did it slow down and then it stopped?
7. S6: Because of the resistance of air.
8. S4: So there was a force.
9. James: So there is a force.
10. *S2: Friction.*

(L4)

The students’ responses to the teacher’s questions (utterances 2-3) were considered as providing information to the teacher and the rest of the students in the group. In this example, ‘Providing Information/Evidence’ also revealed how S6 did not realise there were still forces acting on the trolley even after the teacher stopped pushing it forward. Then, through the teacher's prompt for justification (utterance 6) and S4's comments, S2 suggested the force of friction as another force that was acting on the trolley as it moved. In contrast to the use of 'Providing Information/Evidence', the times that students requested information or evidence from the other members of the group were less, although present in all lessons (Table 8.20). The act of students asking each other questions when they were having difficulty with a task was a strategy that the department of the school was trying to embed in the students' practices, as discussed in Chapter 6, Section 6.2. In some cases, this strategy seemed to be taken up by the students, as in Lesson 4 where students asked each other the most questions, as shown by their use of 'Requests Information' and 'Requests Justification' (Table 8.20). In many instances however, 'Requests for Information' was not addressed to other members of the group but to the teacher, as these requests were related to scientific concepts such as 'uniform acceleration' (L3), 'net force' (L4) and 'mass' (L10).

'Explanation' was another epistemic operation identified in the students' talk and was utilised by students whilst they attempted to explain an event as a response to their teachers' prompts to do so, as in the following example, where the students attempted to explain the movement of an object based on the forces acting upon it.

> 'S6: His hand, I think….his hand is causing the force and because his hand is stronger than gravity [it] holds onto,
> S2: The trolley, his hand is stronger than the trolley,
> S6: Yeah because…and air resistance slows it down'
>
> (L4)

Students' attempts to explain a phenomenon were not always successful because of misconceptions they had on the concepts discussed or difficulty with understanding the task in hand. The lessons in which students utilised the epistemic operation of 'Explanation' were Lessons 4 and Lesson 10 with 2 instances in each, and Lesson 13 with 3 instances of 'Explanation' found (Table 8.20). This is because during the particular lessons students were asked explicitly to explain the movement of the trolley pushed by the teacher based on the forces that acted on it (L4), to explain how mass, weight and gravity changed as an astronaut travelled from the Earth to the moon (L10), or students were given a worksheet that prompted them to explain their answers in Lesson 13 (Appendix G).

Students' attempts to explain an event or phenomenon were based on a given position and some justification or causal link between the ideas they were trying to explain. In other cases, students' providing a position or a claim and justification or evidence to support that claim were categorised as 'Argument' since the students were attempting to state why they thought a statement was correct or not. In the following extract, this pair of students were discussing whether the statement 'the net force is always in the same direction as the ball is moving' was true or false in Lesson 4.

1. S3: That's not false. That's not false.
2. S4: It's false.
3. S3: That's false? That's not false.
4. S4: The overall force is….
5. S3: Always in the same direction; no because it's got friction, that's part of…
6. S4: Yeah but it's stronger,
7. S3: Yeah but that's the overall force we are talking about.
8. *S4: The overall force on the ball. You have the forces to put them altogether so if it's going forward it will probably got [inaudible]* I'm not….Sir, sir?
9. S3: Why is it false?
10. S4: Because the net force is in the direction,
11. [James goes to them]
12. James: S4, did you ask me something?
13. S4: Yeah, will that be true?
14. James: Why do you think that's true?
15. S4: Cause the net force is in the same direction as the ball [inaudible]
16. James: Is it?
17. S4: I don't know.
18. S3: I said false.
19. James: So you don't agree. Why do you think it's not f…true?
20. *S3: Because the overall force and that includes air resistance and all that, so when it's in the air, there is air resistance and air resistance isn't going to the way that the ball is moving.*

(L4)

In this instance, students had a disagreement as they supported opposing views on whether the statement was true or false (utterances 1-3), which they then attempted to resolve. In utterance 8, S4 attempted to state an argument for his claim that the net force on the golf-ball would always be in the same direction as the movement of the ball. However, when he started realising that he was not able to express his idea, he immediately appealed to the expertise of the teacher calling him over to their group instead of trying to discuss the issue with S3. The contribution of the teacher in this case is critical as he prompted S4 to provide a reason for his belief (utterance 14), something that S4 attempted to do earlier but was not successful (utterance 8) leading him to give up the effort and call for his teacher. In fact, James' suggestion of a counter-position in utterance 18 and his insistence on prompting for an argument from the students (utterances 14, 19), made S3 provide a justification, which along with his claim can be considered as an argument (shown in italics).

Overall, the students' use of 'Argument' was not present in all the argumentation lessons observed, although the lessons were organised around activities that required students to form and present their own arguments on different subjects. It seems that students did not so much engage in argument construction during which they would, at least, take a position and also provide evidence or reasons to support that position. What they seemed to be doing, especially when working in pairs, and without the presence of the teacher in their group, was proposing and taking positions (Tables 8.19 and 8.20), which involved one student proposing an answer/claim and the other student either agreeing, in which case they would move on to the next step of their activity without any negotiation or provision of evidence. This was the case in the example below in Lesson 3 (Appendix G).

> S2: I think it's 8A but I don't know what it means but it can't be ignored [8a: The air resistance force on the box is much smaller than the force of gravity, and so it can be ignored]
> S1: It's like you don't pay too much attention to it.
> S2: I think it's that [8a] but we'll leave it out.
> S1: Yeah'
>
> (L3)

In this example, S2 proposed a position stating her opinion, although she also admitted that she did not understand the statement. S1 attempted to help S2 understand statement 8A by making an analogy for the word 'ignore' but still they were unsure about the meaning of the statement so eventually they took a position without providing any reasons for it and moved on to the next set of statements.

Nonetheless, there were cases where students were able to use 'Proposing position' or 'Taking Position' in combination with epistemic operations such as 'Providing Justification' or 'Explanation', which made their talk more epistemic. For example:

S6: This [statement A] is false *because there is also gravity acting on it.*
S2: Let me see…I think it's false.
S6: Shall I write it down?
S2: Yeah.
[S6 writes their answer]
S2: This [statement B] is true. I think. True *because…it's flying in the air for a long, long time.* Want me to write that?
S6: Yeah. Yeah.

(L4)

The difference in the epistemic operations utilised in the first and second example provided above (L3 and L4) seemed to be the fact that during Lesson 4, students had a constant reminder of the fact they needed to provide reasons for their decisions, through their worksheet. This prompt supported students providing justifications along with their opinions, an action that students were not often observed making spontaneously, unless their teacher was present to facilitate the use of epistemic talk, as in the extract from Lesson 4 (p.252).

8.5.2 Students' Attempts to *Justify* Knowledge Claims

The epistemic practice of justifying knowledge claims was present in the students' talk through two epistemic operations: 'Provides Justification' and 'Requests Justification' (Tables 8.19 and 8.20). 'Provides Justification' was applied when a student was providing a reason or evidence in support of an answer and was usually accompanied with the word 'because'. As can be seen in Table 8.20, 'Provides Justification' was mainly used in Lessons 4 and 6, although it was present in all lessons. The students' use of justificatory comments was similar to their teacher's use of the epistemic operations of 'Justification' and 'Prompts for Justification' (Figure 6.6). During the 6 argumentation lessons taught, James utilised the epistemic operation of 'Prompts for Justification' most during Lessons 4 and 5, and he used 'Justification' mostly in Lesson 6.

The nature of justifications provided by the students varied as sometimes students would use justifications based on the authority of the teacher such as 'because of what he [the teacher] said'. In other cases, students would utilise evidence to support their answers as in the following extract from Lesson 6, during which students were asked to select information given to them as evidence in support of their argument [pesticides are a problem and should not be used by farmers] and then, to think of, and rebut other groups' arguments [pesticides are not a problem and should be used by farmers].

> 'S2: So, some scientists think there is no safe level for pesticides…that could be one.
> S1: Yeah.
> S2: And then we can say that […] pesticides cause brain and nerve damage to humans. And, pesticides build up as you go up the food chain.
> S1: Yeah'
>
> (L6)

The epistemic operation of 'Requests Justification' was present 26 times in four of the argumentation lessons (Tables 8.19 and 8.20) and was mainly used when students were asking each other 'why' questions or prompted the provision of a reason from other students that made a claim. This epistemic operation was not facilitated by the presence of the teacher at the group since only one of the 26 instances was identified when the teacher was at the students' table. The students' action of requesting each other for justifications is important as it demonstrates the students' active involvement in epistemic discourse. Students that are in a position to request for justifications demonstrate through their discursive actions an understanding for the role of justification in science and its importance in argument construction. For instance, in Lesson 6, after students worked in their pairs to construct their arguments, they were asked to join other pairs that had to construct the same argument as them, and to join their answers as to make an overall argument to present in whole-class at the end of the lesson. The following is the discussion that one group had:

1 S12: Let's just go through the things we are going to say.
2 S10: I'm not saying anything.
3 S9: Basically pesticides are bad for you.
4 S10: Yeah they can kill you.
5 S6: And it takes longer,
6 *S10: Yeah, but we have to have evidence*.
7 *S11: Why?*
8 *S9: Why?* Because look, pesticides may cause brain and nerve damage,
9 S6: And it takes longer to digest.
10 S12: Yeah.
11 S11: Yeah but you have to expand on it, you can't just read off the statement.
12 S9: Yeah but still it's bad.
13 S6: And if [inaudible]
14 S11: So if you're pregnant and you eat pesticides then the baby will get them as well.

15 S9: Yeah because if you eat them you are giving them to the baby as well. If you had a cow and the cow ate the [inaudible] and then you ate the cow you will have pesticides inside of you.

(L6)

During this group discussion, students started constructing their argument providing a position (utterances 2-4) and as S6 started reading one of the statements written on their worksheet, S10 made an explicit reference to the need to include evidence in their argument (shown in italics). Moreover, S11 perceived and re-stated S10's explicit request for evidence with the question 'why'. This would suggest that this student showed an understanding of the need to justify their viewpoint and that the way to do so would be to try and answer the question why by not only providing some of the statements given to them but also by 'expanding on it' (utterance 11). As a result, students were able to provide two examples of how organisms that consume pesticide chemicals maybe in danger (utterances 14-15) and thus, provide further support for their argument. During the same lesson, students at a different group were discussing which aspects of their argument should be presented.

16 S2: I'll say we are the green hat and then I'll say this thing [position of group], and then I'll say,
17 S1: We are against,
18 S2: Do I say we justify it?
19 S1: No.
20 S2: What do I say?
21 S13: You say your viewpoint, what you think.
22 S2: Our viewpoint is…and then I will say our [pieces of evidence]. What's ours?
23 *S13: You say our viewpoint and then you proven it, give it evidence, like why, why you think that.*
24 S14: It's like pesticides kill useful insects,
25 S2: …and that is bad because…Oh I know, I'm going to say pesticides build up as you go up [the food chain]
26 *S15: And give evidence such as sometimes bees give honey…*

(L6)

In the above group discussion, because the content was made available to the students through the worksheet with the evidence statements (Appendix G) and students had already been given the opportunity to explore and discuss the evidence in pairs, they were then ready as a larger group to consider how their argument should be structured. As shown by their discussion, students were aware that they needed to have a viewpoint, which is their own position on the issue, and that this viewpoint needed to be justified or as S13 stated they had to ‘prove’ their viewpoint by providing evidence to show why they supported that particular point (utterances 21-23, shown in italics). In this sense, it could be argued that students were secure about their content knowledge of the topic discussed, which gave them the opportunity to focus on the structure of an argument and consider the elements that should be included in their argument.

What is more, the two extracts provided in above from Lesson 6, were the only time in the six argumentation lessons that students used meta-language such as ‘prove’, ‘justify’ and ‘evidence’ during their group discussions and were reflective on the process of argument construction. The students’ use of meta-language during their group-work in Lesson 6 could be the result of the fact that the students were given time in smaller groups to think about, and construct their arguments before they were asked to form larger groups and join their arguments to create an overall argument. Another special figure of Lesson 6 was the fact that students were familiar with the content knowledge discussed and they were provided with evidence statements that they could use for their arguments. This lesson was used an end-of-unit lesson which combined the content knowledge that students learnt in previous lessons with a socio-scientific issue (whether farmers should be using pesticides). This meant that students were aware with the content they had to discuss and thus, more secure about their ability to use this content in argumentation activities. Finally, the fact that this lesson had a focus on counter-argument, meant that students had to consider alternative viewpoints and ways of rebutting those views, which could have facilitated students’ explicit mention of ‘evidence’ and the need to justify their viewpoints.

When students were not so secure about their content knowledge, as shown by the uncertainty with which they approached the task and the questions they asked each other about the task, they focused on providing justification and requesting information instead. When students were asked to share their results with other pairs, they continued their activity with conversations focusing on which should be the justification for their answer and the negotiation of knowledge claims was on-going. For instance, in the following example from Lesson 4, students S3 and S4, had to share their results from their pair discussion with the whole group. In this case, students were discussing the statement ‘the force from the golf club acts on the ball until it stops moving’.

1 S4: It's true.
2 S3: True.
3 S5: It's false.
4 S3: Give us the reason.
5 S5: Even if it stops there is still gravity acting on it.
6 S3: Gravity is the same as weight…for the second one. What did you say before?
7 S5: It's false.
8 S3: The second one?
9 S5: Yeah.
10 S3: But it says the force from the golf club… […] Yeah, so about the second one, it's the force from the golf club not any other force.
11 S5: Yeah and there's gravity that makes it slow down.
12 S3: Gravity is the same as weight for the second one…

(L4)

In the extract provided above, students seemed to engage in the process of argumentation whilst attempting to construct their own knowledge of the issues discussed (relation between weight and gravity), which was a distinct approach to the one described earlier in Lesson 6 where students already had knowledge of the topic discussed, as it was taught in previous lessons. Both ways in which students attempted to engage in argumentation and provide justifications for their knowledge claims are valuable as they are the result of distinct approaches to the utilisation of argumentation as a teaching approach to science.

8.5.3 Students' Attempts to *Evaluate* Knowledge Claims

The epistemic operations utilised by students that present their attempts to engage in evaluative processes of knowledge claims are 'Evaluation', 'Requests Evaluation', Counter-Position' and 'Compare & Contrast'. The most commonly used of these epistemic operations was 'Evaluation' during which students made judgments about statements such as whether they are true or false (Lesson 4) or which is the correct one on a flow chart (Lesson 3). If students disagreed then they would discuss the statement further providing some justification of their beliefs, as they managed to do in Lesson 4, presented below.

1 S3: We got false for the first one [the only forces on the ball, once it's been hit by the club, are its weight and air resistance].
2 S7: We got true.
3 S8: Yeah, we got true.
4 S3: Why?

5 S8: […] I told you it was false at the first place.
6 S7: What's the other forces then?
7 S3: OK. Gravity.
8 S4: Gravity, there is a force…
9 S7: Gravity isn't a force, gravity is with weight.
10 S3: Yeah, put there is a push…from a push…
11 S4: And there's the wind, and there's the wind…
12 S7: Wind….air resistance yeah.
13 S4: Air resistance slows the ball down. Wind speeds.
14 S3: Air resistance, look, the ball is going up and that's the air resistance pushing back on it and it still goes forward…

(L4)

Students initially stated their positions on statement A, which were opposing, resulting in S3 requesting for a justification from students S7 and S8. This pair did not provide a justification as they did not seem to be in agreement between them and so, they requested students S3/4 to justify their own evaluation of the statement by providing other forces that could be acting on the ball as it was moving, besides its weight and air resistance (utterance 7). Even though initially, the reason that S3/4 provided was rebutted by S7, who expressed a counter-position to the students' reply (utterance 9), both pairs seemed to reach to an agreement after students S3/4 provided more examples of forces that could be acting on the ball as it moved, such as a push (possibly from the golf club) and from wind travelling in the same direction as the movement of the ball. During this negotiation of the validity of statement A, students were able to utilise the epistemic operations of 'Evaluation' in utterances 1-3, 'Requests Justification' (utterance 4), 'Requests Evidence' (utterance 6) and 'Counter-position' along with 'Provides Justification' (utterance 9), engaging in this way in epistemic talk of a higher epistemic level. This was in contrast to other instances of evaluating and sharing results, where students only provided their opinion when evaluating statements, and did not elaborate further either by providing evidence or other types of justifications. A possible explanation for the quality of epistemic discourse observed in this example is the fact that students were first given time to consider and think about their reasons in pairs before they moved on to sharing with other pairs their results and evaluating each other's responses. What is more, students had to write their reasons on the worksheet provided, which meant that they then had a basis for discussion, which could have facilitated the development of epistemic discourse.

Students also utilised the epistemic operation of 'Requests Evaluation' during which they asked other students to state their views on the statements that they had to evaluate. However, the majority of instances of this discursive action were found during Lesson 4 (12/15 instances). What is more, most of the requests from students for an evaluation were asking other students for their answers on statements they had to evaluate, such as ‘what did you get from the third [statement]’, or were addressed to the teacher when students found some statements to be difficult, such as ‘sir, can you tell us if this is right’. However, there were some instances, where the function of ‘Requests Evaluation’ (shown in italics below) was more epistemic, as in the following example from Lesson 4 with students S3 and S4 discussing statement D (the force from his or her drive wore off at the point where the ball started to drop).

1 *S3: Is that true?*
2 S4: [yes]
3 S3: What’s the reason for that?
4 S4: [indicates he does not know] It’s true though.
5 S3: Because when it stops it has natural force. *Is that right?*
6 S4: No, as long as it moves…
7 S3: It only has,
8 S4: …as long as it’s moving,
9 S3: … it only has the force of the golf club when it’s moving.
10 S4: [yes] As long as it’s moving the force it’s still there. (L4)

‘Counter-Position’ was an epistemic operation, which although found to be commonly used by the students (51 instances, Table 8.19), it took mostly the form of proposing a position that was different/opposing to the student’s pair or other students’ positions without necessarily providing any reason or justification for this difference in opinion. From the 51 instances that ‘Counter-Position’ was identified in the students’ talk, 25 instances were accompanied by a justification or evidence that would function as support for their intention to disagree with a position, and most of those 25 instances were located in Lesson 6 (12 instances) since students were given pieces of evidence that they could use to counter-argue. The fact that students’ were able to provide evidence or justification in support of their viewpoints in those 25 cases is consistent with their ability to coordinate theory and evidence as discussed in Section 8.3.1. During Lesson 6 and Lesson 4, students were explicitly asked to express their evidence and reasons. This would suggest that students are able to provide evidence when requested, although they do not justify their views spontaneously, either because they do not see the need to justify their positions or because they do not consider it as important to do so (Sandoval & Millwood, 2005).

Moreover, as can be seen in Table 8.20, the epistemic operation of ‘Counter-Position’ was identified mostly in Lesson 4 (19 instances), Lesson 6 (16 instances) and Lesson 3 (11 instances) whereas for Lessons 5, 10 and 13 it was used only once or twice by the students. That is because students in Lessons 3, 4 and 6 were encouraged to express opposing positions as they were sharing results or constructing their arguments whereas counter-argument was not an aspect that Lessons 5, 10 and 13 dealt with in any way. This pattern is consistent with the teacher’s talk and the ways in which he utilised the epistemic operations of ‘Counter-Argument’ and ‘Prompts for Counter-Argument’ during these lessons (Appendix H). Namely, the teacher’s use of ‘Counter-Argument’ and/or ‘Prompts for Counter-Argument’ were present mainly in Lessons 3, 4 and 6, which could have facilitated the students’ use of these discursive actions.

During the six argumentation lessons observed as part of the first case study, the students used similar epistemic operations to those of their teacher. In constructing their knowledge they mainly requested or provided other students with information that would help them construct their arguments. They also provided justifications and prompted each other to provide justifications through questions such as ‘why’. Evaluative processes were present usually when students expressed an opinion about whether a statement was true or false, or when they requested for an evaluation from the other students of the group, although this feature was not present to a great extent in the students’ talk. Finally, students were found to propose different ‘counter-positions’, although these were not always accompanied with a reason in support of the counter-position put forward. The ways in which the epistemic features of the students’ talk relate to their teacher’s talk during the same lessons will be discussed in the next section.

8.6 DISCUSSION

This chapter has explored students’ formal and personal epistemologies through individual interviews of a group of four students and provided a picture of the types of talk and interactions that this group of students engaged in during argumentation instruction. In particular, as discussed in Sections 8.2.1-3, during the first set of interviews students seemed to consider facts as the overall objective of the scientific practice, which could be the result of the manner in which the connection between facts and scientific theories was presented to them. Facts are an important aspect of science, and of science education, since they constitute part of the science students are taught at school. Yet, science should not be presented as constituted solely of scientific facts since:

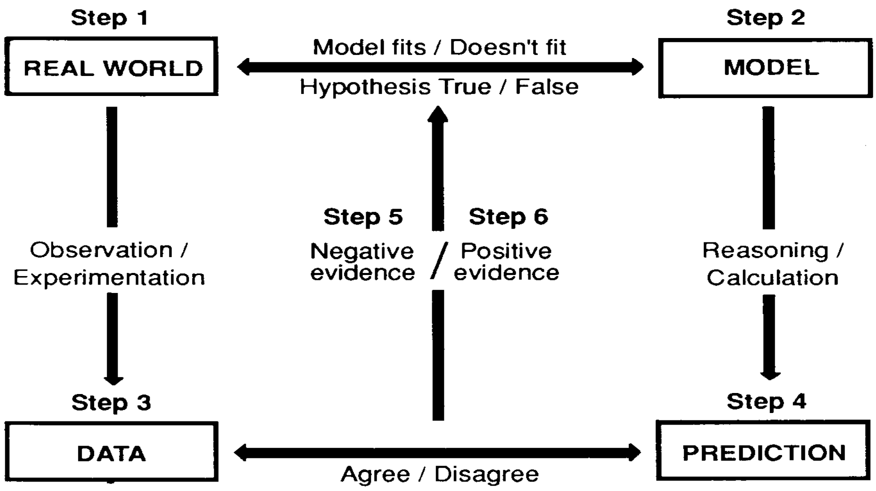
> ‘any education that focuses predominantly on the detailed products of scientific labour – the facts of science – without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science’ (NRC, 2011, p.42-43).

Thus, facts should be used to help students make their own arguments and explanations in the science classroom and help them develop their understanding of scientific concepts. Moreover, students were not able to consider theories in science as explanatory mechanisms and tended to use the word ‘theory’ in its everyday sense, an action that was similar to their teacher’s practice, who as mentioned earlier, he did not make any reference to scientific theories as explanations during the lessons he was observed teaching.

During the second set of interviews students seemed to be able to consider the role of facts in science not only as the overall objective of the scientific enterprise but also as information that could be utilised as evidence to support a viewpoint, or to prove an idea correct. What is more, students’ understanding of experimentation and proving in science seemed to shift from a direct link of an experiment to an answer towards modelling scientific experimentation as an experiment to gather evidence to get an answer. In fact, students’ understanding of the notion of evidence and their role in scientific practices was more evident during the second set of interviews (Sections 8.2.3 and 8.2.4). This is consistent with their teacher’s practices as described through the 13 lessons observed through the school year. During those lessons, James placed emphasis on the notion of evidence, used the term regularly in his classroom talk and explained how evidence is used to support ideas or ‘rubbish’ them through providing opposing claims and arguments (as discussed in Chapter 6).

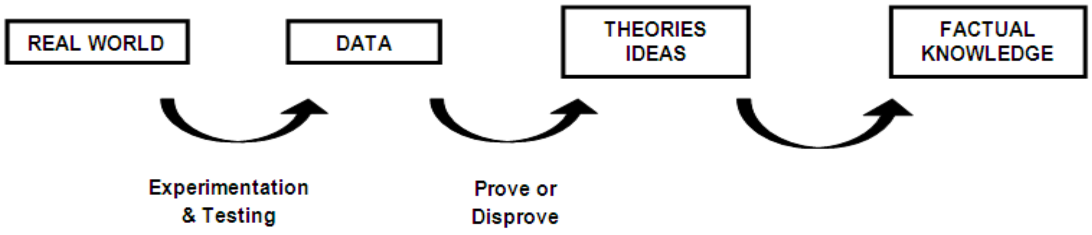
The students’ views of the practice of science can be compared to Giere’s (1991) model of scientific practices as presented in Figure 8.24. According to Giere (1991), the different models scientists create are based on the real world and it is the scientist’s responsibility to ascertain whether a model fits or does not fit the real world. These models are utilised for making predictions, which are then compared to the data gathered through experimentation and observation. If the data agree with the predictions made based on the theoretical models of the scientists, then they constitute positive evidence that increase the possibility of the model fitting the real world. However, if the data collected disagree with the predictions made based on the model, then there is negative evidence that works against the model as a representation of reality and scientists need to readjust, improve or completely reject their theoretical models or explanations and construct new ones.

Figure 8.24: Giere's (1991) model of the practice of science



When comparing the students' responses from their interviews to Giere's (1991) model of scientific practices, it seems that Step 2 is missing from the students' discussion of scientific theories, since as discussed in Section 8.2.1 students did not seem to conceptualise scientific theories as explanatory frameworks and models of the physical world. Moreover, during the first set of interviews students seemed to be less concerned with Steps 5 and 6 of the model above, about whether the data collected through investigations function as positive or negative evidence for the model to fit. As mentioned in Section 8.2.3, students viewed facts as the end-result of science (learning) and as a direct representation of reality, since the thematic categories of 'proven theories become facts' and 'facts are true/real' were present in all the student interviews conducted. In fact, students' formal epistemologies focused mainly on Steps 1 and 3. Students' representation of the practice of science as was presented through their first set of interviews is presented in Figure 8.25.

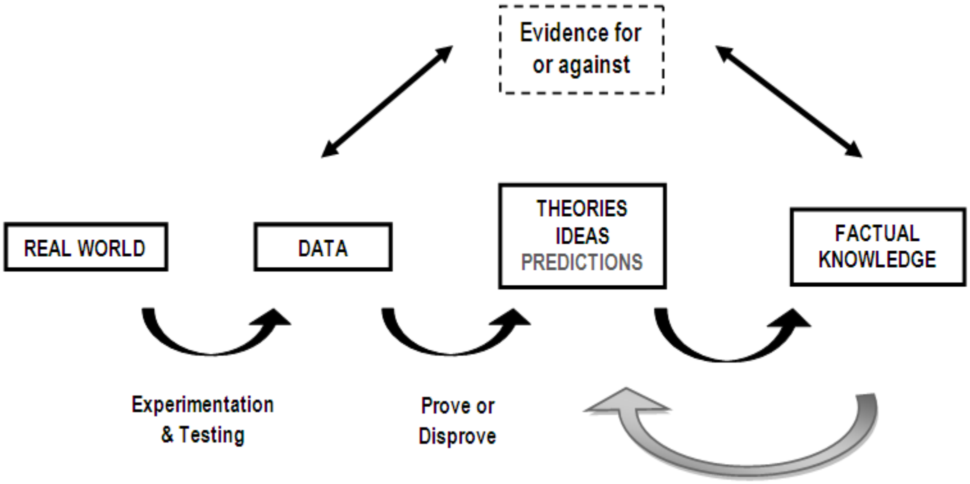
Figure 8.25: A representation of students' understanding of the practice of science in the first set of interviews



Based on the students' understanding presented in Figure 8.25, there is a linear progression in the acquisition of facts from the physical world. Particularly, factual knowledge corresponds to the real world from which data is collected through experimentation and testing in order to prove ideas or predictions as true or false. If these ideas are true then they become factual knowledge and if not, then they are either discarded or reworked to fit the data. The representation of scientific practices in Figure 8.25, views theories through the everyday use of the word 'theory' and not through the accepted by the scientific community view of theories as explanatory mechanisms. Moreover, there exists an understanding of a correspondence view of scientific knowledge, where this knowledge directly corresponds to the real world, to what is out there (Carey et al., 1989; Sandoval & Morrison, 2003). In the second set of interviews students seemed to do better in realising the need for using Steps 4, 5 and 6 in the practice of science.

In fact, as shown in Figure 8.26, students during the second set of interviews were better able to consider how the data collected through experimentation and testing can be utilised as evidence to support or reject ideas and thus create facts. Moreover, the understanding that facts could initiate an investigation also emerged, since examining facts might lead to the creation of new ideas or theories that would need to be tested. Finally, the predictive nature of theories also appeared in this representation as part of scientific practices.

Figure 8.26: Students' understanding of the practice of science through the second set of interviews

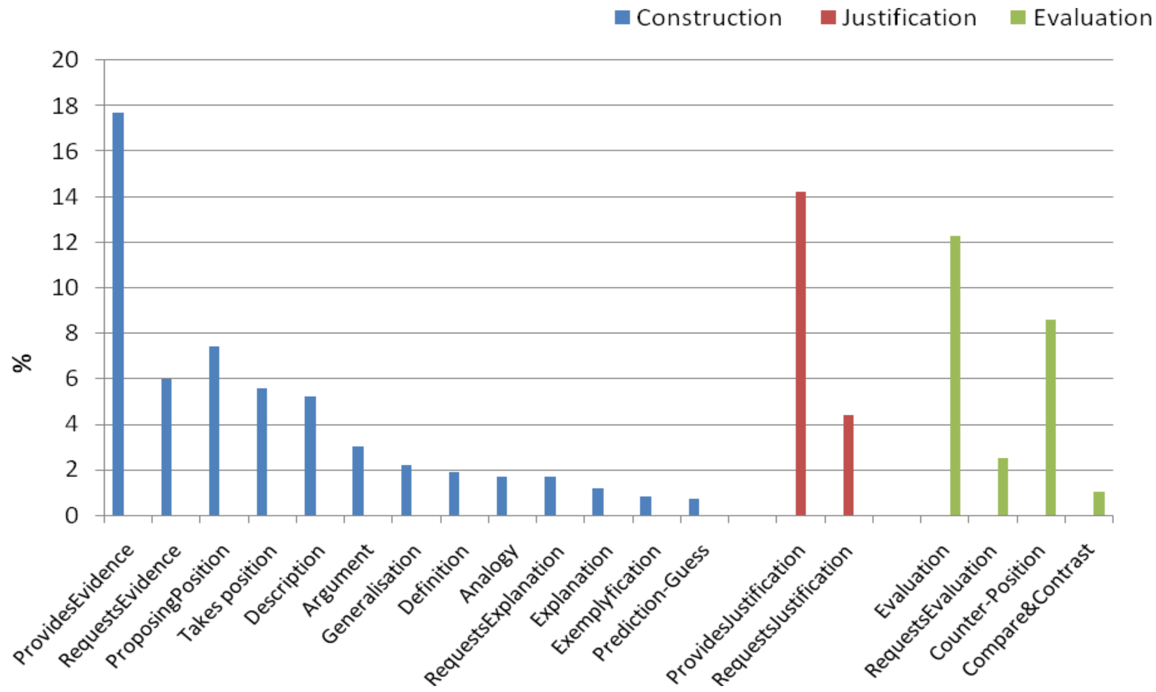


The students' practical epistemologies were characterised by students' ability to provide their own empirical evidence to support their views and coordinate theory and evidence. In particular, students during the second set of interviews, seemed to had improved their ability to coordinate theory and evidence as they were able to provide evidence-based reasoning for their views, and the provision of evidence was not only characterised by direct perceptual evidence but also by the use of indirect evidence and inferential thinking (as discussed in Sections 8.3.1 and 8.3.2). Moreover, some of the students showed an increasing ability to not only provide evidence for their views, (evidence which is consistent with the theory they are talking about) but also evidence against them, as discussed in Section 8.3.1 about how students responded to Task 1 and Task 3 (evidence against Theory 1, evidence against statement in Task 3 etc.). This ability to state reasons for why a claim is wrong further supports the view that students improved their reasoning ability, as considering opposing views is more challenging than attempting to support a viewpoint. The ability to coordinate theory with evidence is an ability that develops with age, but it also needs to be cultivated and developed as a skill (Driver et al., 1996; Kuhn 2005; 2009). One possible explanation for the students' improved ability to use direct and indirect evidence and coordinate theory and evidence successfully could be the students' engagement with argumentation during the school year. However, it should also be noted that the nature of this study is not able to provide any causal links for the use of argumentation in science education and how this helps students develop their understanding of the NOS.

The students' ability to coordinate theory and evidence, as shown through their interviews, was also evident in their classroom interactions, as shown by their use of epistemic operations such as 'Provides Justification' and 'Provides Evidence/Information'. The students' discursive actions or epistemic operations showed that students were able and willing to provide and take positions and counter-positions when talking in the groups but they were not always able or willing to provide justifications whilst talking, since they did not always justify their views. Figure 8.27 presents the epistemic operations utilised by the group of students observed during James' argumentation lessons. These were organised based on the construction, justification and evaluation of knowledge claims, as discussed in the previous sections of this chapter (Sections 8.5.1-3).

A comparison of the students' use of epistemic operations whilst talking in their pairs or groups, as demonstrated in Figure 8.27, to the ways that their teacher talked during the same argumentation lessons (Figure 6.11) and during the non-argumentation lessons he taught (Figure 6.12), shows that the student talk resembled the teacher talk during non-argumentation lessons in terms of the constructive aspect of epistemic practices. That is, students, as their teacher during non-argumentation instruction, focused mainly on providing and asking for information/evidence and not so much on providing arguments, explanations or using analogies. This is not surprising as the epistemic operations that James utilised during argument-based instruction focused on providing students with information and content through various epistemic operations such as 'Generalisation', 'Description' and 'Exemplification' that would be necessary for the students' task.

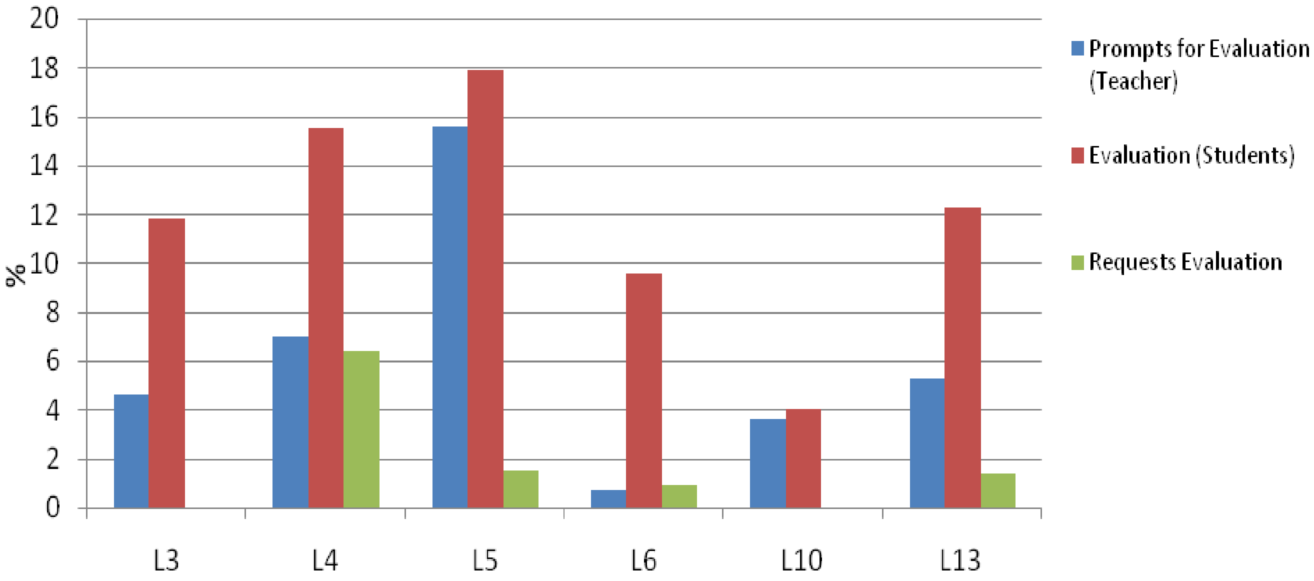
Figure 8.27: Students' epistemic operations in the six argumentation lessons of Case Study 1



The function of students' talk during argumentation lessons was to construct arguments, which meant that epistemic operations such as 'Taking Position', 'Proposing Position' and 'Provides Evidence/Information' were dominating the student discussions. Yet, the students' use of the epistemic operation of 'Argument' was not a strong feature of their talk. As discussed earlier (Section 8.5.1), students mainly provided claims and positioned themselves on an issue, but those claims were not considered as arguments, as they were not usually accompanied by some justification or reason in support of the claim. This would suggest that although students were engaging in argumentation activities, their argumentation skills were not developed to the point where students would provide full arguments (consisting of claims and justification), without any prompts or facilitation.

The students' use of justificatory and evaluative comments was similar to their teacher's use of the epistemic operations of 'Justification', 'Prompts for Justification', 'Evaluation' and 'Requests Evaluation' during argumentation lessons. Figure 8.28 presents in detail, the 'Prompts for Evaluation' that James utilised during each of his argumentation lessons and the evaluative comments that his students made in their groups during the same lessons. The epistemic operations are provided as a percentage of the total epistemic operations found in each lesson. As can be seen in Figure 8.28, the teacher prompted students to engage in evaluative processes in the lessons observed, with the exemption of Lesson 6.

Figure 8.28: The use of 'Prompts for Evaluation' by James and his students' use of evaluative comments in the six argumentation lessons of Case Study 1



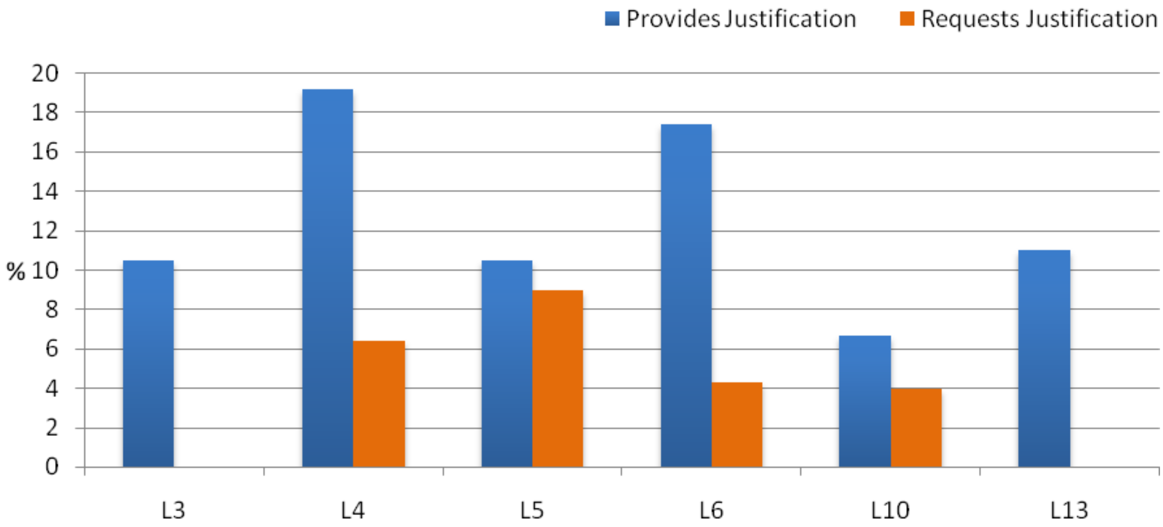
Accordingly, students engaged in the discursive actions of 'Evaluation-Students' and 'Requests Evaluation' in the same lessons as their teacher. Specifically, the teacher's increase of 'Prompts for Evaluation', was also followed by the students' increased use of 'Evaluation' and 'Requests Evaluation', in Lessons 3, 4 and 5, where students had to make a judgment as to which of the statements given to them was the best (Lesson 3), evaluate statements as true or false (Lesson 4), or, make a judgment as to which line on a graph was oxygen and carbon dioxide (Lesson 5). This would suggest that the evaluative comments in the teacher's talk influenced the students' engagement in evaluative processes and their talk during the lessons observed. It was also noted that the students' use of 'Requests Evaluation' was not always present in the lessons observed. Rather, it was dependent on the context of the lesson. For instance, one of the lessons where students and teacher used the most evaluative comments (Lesson 4) focused on the process of evaluation by providing students with statements that they should evaluate as true or false and then provide reasons that would support their judgement. In Lesson 4, the facilitation of evaluation was not only undertaken by the teacher, as shown by his discursive actions, but also from the worksheet that the students had to use, which requested a written reason for the students' judgements. As a result, the context and structure of the lesson influenced the students' engagement with epistemic discourse.

Nevertheless, as discussed in Section 8.4.3, and as shown by the inconsistent use of 'Requests Evaluation' in Figure 8.28, the students' evaluative judgements often were not accompanied with any justificatory comments that would indicate the use of epistemic talk in those cases. Similarly, as shown through the extracts provided in Section 8.4.3, students were in a position to state counter-positions to the ones that their classmates were expressing, but once again, this initial reaction to disagree or express an opposing view, was not always accompanied by further elaboration of the reasons that led to their disagreement. Students were able to provide justifications for their counter-positions, mostly in Lesson 6, where they were given on a worksheet the evidence statements they could use to construct their arguments. Again, the facilitation of the process of justification through artefacts such as the worksheets provided, increased the level of epistemic talk taking place during the students' group-work activities.

Another point to make is the discrepancy that seemed to exist between the use of the epistemic operations of 'Provides Justification' and 'Requests Justification' (Figure 8.29). The former was utilised more in the students' talk as they were shown to provide justifications usually through the provision of evidence to support their viewpoints. However, the use of the epistemic operation of 'Requests Justification', which was used less from these students, showed that students did not spontaneously engage in such practices and that their requests for justification depended on the context of the lesson, as was their use of 'Requests Evaluation'.

Students were able to provide justifications for their views when asked by other students or their teacher or, when prompted through the worksheets they worked on. Yet, as in the case of the epistemic operation of 'Requests Evaluation', students were not taking initiatives in requesting for justifications consistently, as shown in Figure 8.29, which would allow for the development of epistemic talk within their group. 'Requests Justification' and 'Requests Evaluation' are considered as an explicit attempt by the students to engage in justificatory and evaluative practices. These epistemic operations have a higher epistemic status compared to epistemic operations such as providing evaluations and justifications, since students acknowledge the need to ask 'why' questions and engage in critical evaluation of knowledge claims.

Figure 8.29: Students' discursive actions of providing and requesting justifications during argumentation lessons



Finally, the way that 'Requests Justification' and 'Requests Evaluation' were used by the students, suggests that these processes need to be facilitated not only by the teacher's own discursive actions, as was the case in this teacher's use of 'Prompts for Evaluation' (Figure 8.28), but also by other means such as the worksheets that the students are provided with, for the students to engage in justificatory and evaluative processes.

On the whole, the evidence from the students' classroom talk during the six argumentation lessons observed would suggest that students (a) were able to, and, engaged in epistemic talk, as shown through their use of justificatory and evaluative comments (Figures 8.27 and 8.28), (b) even in argument-based instruction, students not always justified their ideas, unless this action was facilitated by the teacher or a prompt such as a worksheet, and/or the students were secure about their content knowledge of the issue discussed (c) the epistemic talk that took place during argument-based instruction was context-specific, as the aim of each lesson provided a focus for the types of talk that developed.

8.7 SUMMARY

This chapter focused on the students of Case Study 1 and provided a description of four students' understanding of the nature and role of theories and evidence in science, as elicited through interviews. The results from the interview data suggest that there was some improvement of the students' formal epistemologies in terms of their views of the role of evidence in science. Moreover, the students' practical epistemologies were investigated through the interviews. Students were found to be able to coordinate theory and evidence in the Tasks provided. Improvement was detected on students' ability to use direct and indirect evidence to support their views during the second set of interviews, and also, in providing disconfirming evidence for claims in addition to confirming evidence, which could be the result of their engagement with argument-based activities. Finally, an analysis of the students' classroom talk during the six argumentation lessons they were observed suggests that the students' talk during these lessons modelled their teacher's talk, as shown in Figures 6.11 and 6.12. This has implications for specific talk moves that science teachers should focus on and attempt to promote in their classrooms, such as prompting students for evaluation, justifications, comparisons and counter-argument. By using more of these discursive actions the teachers would be assisting their students engaging in epistemic discourse that is argued as an essential element of students' ability to develop their understanding of epistemic aspects of science (Sandoval & Morrison, 2003). Finally, the importance of the context for the facilitation of certain epistemic processes such as evaluation/critique and justification suggests that further research in developing in-service teacher's ability to design suitable materials for the teaching of science as argument, is required.

CHAPTER 9

DISCUSSION AND CONCLUSIONS

9.1 INTRODUCTION

This thesis set out to explore the classroom talk that took place in two, secondary school science classrooms. The participating teachers were trained and then attempted to use argumentation as a framework for science teaching and learning. The training of the two teachers in using argumentation was based on Toulmin's framework of argument and attempts to incorporate that into science education (Erduran et al., 2004; Osborne et al., 2004a). Through the analysis of classroom talk that took place during argumentation and non-argumentation lessons for the duration of a school year, specific epistemic features were identified and their function in the development of epistemic discourse in the two science classrooms discussed.

The research questions that guided the study were:

- **RQ1.** What are the epistemic features of science teachers' talk during argumentation and non-argumentation instruction?
- **RQ2.** Does science teachers' epistemic talk change as they participate in a professional development programme that aims to incorporate argumentation into their everyday practices?
- **RQ3.** What are students' understanding of the nature and role of theories and evidence in science, over the course of a school year?
- **RQ4.** What are the epistemic features of students' classroom talk during argumentation activities over the course of a school year?

Through examining the discursive actions of teacher and students during these science lessons this study aimed to describe how the two teachers presented and emphasised the constructive, justificatory and evaluative practices of science through their talk, and how they attempted to prompt students to engage in these practises. This chapter provides a discussion of the epistemic features of the science teachers' classroom talk that emerged from the analysis provided in Chapters 6, 7 and 8. Section 9.2 includes a discussion of the findings of the teachers' classroom talk during argumentation and non-argumentation instruction – in particular, a focus identified by the two science teachers on construction and justification but not on evaluation of knowledge claims. In addition, it was found that argumentation as a framework for science teaching advanced the epistemic talk of the science classroom through promoting evaluative as well as constructive and justificatory practices. Moreover, it was found that the context of argumentation lessons influenced the specific epistemic features that were employed by the teachers in their classroom talk.

Section 9.3 includes a discussion of the role of the teacher and the influence that the teachers' views of the nature and role of argumentation had on the way in which they implemented argumentation into their teaching practices. Other factors that influenced the development of epistemic talk during argumentation-based instruction were the teachers' views of their students' ability to work together and engage in argumentation activities, and the teachers' ability to organise and carry out argument-based and group work activities.

Section 9.4 then provides a discussion of the students' discursive interactions from Case Study 1, which were examined and compared to that of their teacher's, looking for any similarities or differences between their teacher's talk and their own. It was found that the students' talk during argumentation-based instruction paralleled that of their teacher's talk in its use of justificatory and evaluative practices of science. Finally, students' understanding of the nature and role of evidence for the practice of science changed from a view of science as resting on simple facts to one that saw facts as information that could be utilised to support or reject claims. In contrast, the students' views of the nature of theories did not change, as shown through their interviews, with students using the word 'theory' based on its everyday meaning of idea/opinion and being unaware of the scientific notion of theory as an explanatory framework, either before or after. The findings emerging from this study are presented and discussed for their implications for future research directions.

9.2 The Science Classroom as a Site for Epistemic Talk

This section aims to provide a discussion of the findings emerging from the analysis of the classroom talk during both argumentation and non-argumentation lessons by the two participating teachers as to provide answers to RQ1 and RQ2. The classroom talk of these two teachers was analysed and presented based on two frameworks. Firstly, a micro-level framework of epistemic operations where the talk of each teacher was described for its function within the learning process (explaining, arguing, generalising etc.). Secondly, a macro-level framework identifying *which* epistemic operations were contributing towards the construction, justification and evaluation of knowledge claims – all of which are part of the epistemic practice of science (Kelly, 2008) – and, *how* these epistemic operations contributed towards the construction, justification and evaluation of knowledge claims in the science classroom. The discussion of the findings that follows takes into account both frameworks of analysis.

During argumentation lessons, the epistemic practices of construction, justification and evaluation of knowledge claims were all present in the talk of the two science teachers. Although all three epistemic practices were present in the two science classrooms during argumentation instruction, the consistency and extent to which they were presented to students by each teacher varied across lessons. In addition, the analysis showed that the two teachers were able to engage their students in the epistemic practices of *construction* and *justification* of scientific knowledge during non-argumentation lessons, although it was noted that *evaluation* and *counter-argument* were used considerably less throughout the school year in these lessons.

9.2.1 Developing Epistemic Talk Through Constructing Knowledge Claims

For the most part, the teachers' classroom talk was characterised by epistemic features which aimed at constructing scientific knowledge, such as 'Description', 'Explanation', 'Definition', 'Generalisation', 'Argument', 'Prediction' and 'Provides Evidence'. The two teachers utilised these epistemic operations to provide their students with content knowledge, by either reminding them of previous lessons or introducing new concepts before they went on to use other epistemic operations such as 'Justification' and 'Evaluation'. For instance, through the use of epistemic operations such as ‘Description’, the teachers provided students with information that would be necessary in the activities to come in their lessons.

The use of epistemic features such as ‘Description’, ‘Explanation’, ‘Definition’ etc., to contribute in the construction of scientific knowledge, explicate the teachers’ belief of the necessity of providing students with content knowledge. This content knowledge could then facilitate students’ participation in argumentation activities. As von Aufschnaiter, Erduran, Osborne and Simon (2008) maintain, students’ understanding and familiarity with content is critical for their ability to construct high quality arguments. Engagement in the process of argumentation requires content knowledge to be used and understood up to a point, before it can become part of an argument in the form of evidence, warrants or backings for a claim and rebuttals for another claim. Therefore, the epistemic operations utilised for the construction of knowledge claims, could be considered as the basic discursive actions and reasoning processes that the teachers presented to their students. These epistemic operations aimed at facilitating the students’ participation in the learning process, before moving on to more cognitively challenging activities such as the evaluation of knowledge claims. In this sense, the process of construction is a fundamental a priori necessity for students’ learning. What is more, the epistemic operations used as part of constructing knowledge claims could be considered as prerequisites for arguing since through these epistemic operations students would acquire or develop their understanding of concepts they are then asked to argue about.

The non-argumentation lessons observed were characterised by similar epistemic operations to the argumentation lessons, although the rate of occurrence and emphasis placed on epistemic operations such as ‘Argument’, ‘Provides Evidence’, ‘Counter-Argument’ and ‘Description’ were different to that of argumentation lessons. In particular, epistemic operations such as ‘Provides Evidence’ and ‘Description’ dominated the talk of both teachers when their teaching was not based on argumentation. As was presented in Figures 6.12 and 7.19, during non-argumentation lessons, a shift towards the epistemic operations of ‘Provides Evidence’ and ‘Prompts for Evidence’ was apparent, at the expense of the utilisation of more cognitively demanding operations such as ‘Argument’, ‘Prompts for Evaluation’ and ‘Counter-Argument’.

This shift towards providing information and evidence to students during ‘ordinary’ science lessons is consistent with results presented by Kovalainen and Kumpulainen (2005), who examined the talk of whole-class interactions in a primary school class not only in science lessons, but also during mathematics instruction and open-dialogue interactions in philosophy for children. Their results indicate that the teacher-initiated talk during the science investigation they observed was characterised mostly by the provision of information or exchanging views and opinions amongst the teacher and the students. The general function of these discursive activities was mainly the presentation of knowledge rather than engaging in reasoning and reflective activities. Kovalainen and Kumpulainen's (2005) results are in agreement with the results emerging from the two case studies of this study where the teachers' talk, especially during non-argumentation lessons, focused on presenting or prompting students with information or evidence. During non-argumentation lessons, less emphasis was placed on reasoning-based talk, such as prompting for arguments and justifications, as shown in Tables 6.5 and 6.6 in Case Study 1 and Tables 7.9 and 7.10 in Case Study 2. In argument-based instruction, the teachers used epistemic operations that were more challenging than merely prompting and providing information to the students. Thus, the findings from this study emphasise the positive influence that structuring science teaching and learning on argumentation had for advancing the epistemic discourse of the science classroom in contrast to everyday science teaching.

9.2.2 Developing Epistemic Talk Through Justificatory Processes

An integral part of both teachers' classroom talk was the epistemic operation of 'Justification'. In James' and Amy's argumentation lessons, epistemic operations became more cognitively demanding and challenging as they started prompting students to provide their own arguments or provide justifications from evidence for their opinions/ideas. 'Justification' was utilised by both teachers, although not to the same extent. The justificatory aspect of the practice of argumentation was the strongest epistemic feature of James' classroom talk, which was also one of the fundamental ways in which he conceptualised the notion of argumentation, as shown by his interviews (Chapter 6, Section 6.2). What is more, James utilised 'Justification' as part of his non-argumentation lessons in a manner and frequency which were not substantively different to that of argumentation lessons (Figure 6.13). In Case Study 2, Amy utilised 'Justification' and 'Prompts for Justification' consistently in her argumentation lessons, although this was not the case for her non-argumentation lessons, especially her use of 'Prompts for Justification', which was minimal (Figures 7.19 and 7.21). What is more, as shown through Figure 7.20, she seemed to be developing her use of ‘Justification’ within the four argumentation lessons she taught, but this development did not transfer to her non-argumentation lessons.

The extensive use of the epistemic operations of ‘Justification’ and ‘Prompts for Justification’ identified in the talk of the two teachers during argumentation instruction suggests that justification is a feature of classroom talk that should be investigated further. The need for further research on the use of justification in the teachers’ classroom talk is even greater given the fact that the few studies that have analysed the epistemic function of science teachers’ classroom talk, do not include the epistemic operation of ‘Justification’ as part of their analytic framework. For instance, a study reported by Jiménez-Aleixandre et al. (2008) in Chapter 3, also utilised Ohlsson’s list of epistemic operations (see Table 3.2) to analyse classroom talk in secondary schools, but although they made special reference to the use of the epistemic operations of ‘Description’, ‘Explanation’ and ‘Generalisation’, they did not mention or explore the discursive action of ‘Justification’. This omission might be due to the fact that justificatory comments or thinking is often part of other epistemic operations such as ‘Argument’ and ‘Explanation’. However, the findings of this thesis suggest that justificatory talk may assist in making classroom talk more epistemic, through generating a demand for justifications and alternative reasons for a claim/opinion, for example, through the use of ‘Prompts for Justification’ and ‘Prompts for Argument’. As a consequence, this study has contributed to the field by documenting the ways in which the epistemic practice of justification appears in the discursive practices of teachers and students in both argumentation lessons and everyday science teaching contexts.

9.2.3 Developing Epistemic Talk Through Evaluative Processes

The discursive actions of ‘Evaluation’, ‘Compare & Contrast’, ‘Counter-Argument’, ‘Prompts for Evaluation’, ‘Prompts for Comparison’ and ‘Prompts for Counter-Argument’ were those that represented the epistemic practice of evaluating knowledge claims in the teachers’ classroom talk. Glassner and Schwarz (2005) report that the ability of students to evaluate critically knowledge claims develops during adolescence and, therefore, if secondary school students are to develop the ability to be critical and evaluative, then their teachers need to be in a position to engage them in such evaluative activities. As noted in Section 9.2, the process of evaluation was underrepresented in the classroom talk examined, both during argumentation and non-argumentation lessons. Even so, the presence of evaluative processes was more evident during argumentation-based instruction, and especially during lessons that aimed specifically at engaging students in making comparisons and constructing counter-arguments.

Glassner and Schwarz's (2005) study focused on Year 9 and Year 11 students (Grades 8 and 10) and their findings suggest that (a) there was a developmental trend in students' ability to provide counter-arguments, and (b) students who expressed their own personal arguments before they moved on to critical evaluation, combined with teachers modelling counter-argument, improved their ability to counter-argue, especially the Year 9 students. Glassner and Schwarz (2005) mention the use of worked-out examples of how to counter-argue by teachers in order for students to develop the skill of counter-arguing, since their Year 9 students that were provided with examples of counter-argument demonstrated an improved ability to counter-argue. Likewise, teachers in the two case studies used epistemic operations such as 'Argument' and 'Counter-Argument' to structure classroom talk and model these processes for their students.

However, the use of the epistemic operation of 'Counter-argument' and the modelling of counter-argument by the two teachers was almost non-existent, especially in non-argumentation lessons. This would suggest that during the everyday teaching practices of the two teachers, there was almost never any plurality of viewpoints or alternatives provided that would have created a need for comparisons and thus facilitate the creation of arguments and counter-arguments as part of the learning process. Moreover, the two teachers used 'Prompts for Argument' and 'Prompts for Counter-Argument' more than they used 'Argument' and 'Counter-Argument', respectively. That is, they were not themselves using the discursive actions that were encouraging their students to use whilst talking and arguing in the classroom. The absence of counter-argument in non-argumentation lessons and the difference between the teachers' own use of counter-argument and their prompts towards the students for evaluation and counter-argument, suggests that the two teachers were not familiar with this type of talking in their classrooms, even if they took part in the professional development programme that aimed at promoting dialogic teaching and argumentation into their everyday practices.

Further evidence of similar findings of the minimal use of evaluative processes in teacher talk is provided by Kang (2007), who through a professional development course to help teachers develop their understanding and use of conceptual change pedagogy, concluded that the participating elementary science teachers needed substantial support in developing their understanding of the role of counter-evidence. Teachers in this project, simply provided counter-evidence to their students believing that pieces of conflicting evidence were able to help students change their misconceptions. These teachers did not perceive the need of confronting their students with the conflicting evidence they provided them, so as to help students realise the existence of a conflict and change their views. Kang (2007) concluded that that ‘to help students develop deeper understanding, teachers need to explicitly compare and evaluate different ideas with their students’ (p.1313). However, as shown in this thesis, the two science teachers did not use any explicit comparison of ideas or evaluative processes whilst teaching science.

Moreover, throughout this thesis, it has been shown that not only beginning teachers such as Amy in Case Study 2, have difficulty with utilising evaluative processes in their teaching practices, as discussed in the Kang (2007) study, but also experienced teachers such as James in Case Study 1, who did not place any emphasis on counter-argument. The similarity in the lack of evaluative processes in the talk of the two teachers of this study would suggest that factors other than the teachers’ teaching experience guide their use of epistemic talk whilst teaching science based on argumentation. These factors could be the teachers’ confidence in teaching argumentation and their views of argumentation as a scientific process and an approach to science teaching and learning. These issues are further discussed in Section 9.3. The absence of evaluation and counter-argument from both teachers’ discursive practices suggests that these aspects need to be emphasised in both initial and in-service teacher training programmes. These training programmes would need to help prospective and in-service science teachers develop teaching practices that not only focus on constructing students’ knowledge but also on helping students engage in processes of evaluating knowledge claims in order to develop a more complete understanding of the epistemic practices of science.

Another issue for consideration is the two teachers’ use of ‘Evaluation’. As discussed in Chapters 6 and 7, this epistemic operation was one of the most common of all epistemic operations found in both teachers’ talk. However, it was also identified that the nature of many of the evaluative comments made by the two teachers was not epistemic but rather, followed the IRE pattern of interaction. This way of talking has been identified as taking up a large part of science classroom talk and can be authoritative in the sense that the teacher is both guiding and judging the outcomes of discussion (Lemke, 1990; Mortimer & Scott, 2003). When evaluative comments had an epistemic function in the talk of the two teachers in this study, these comments were usually accompanied by other epistemic operations that prompted students to consider further evidence or counter-evidence, to provide justifications, or generalisations that provided the chance to other students to contribute to the discussion. Thus, this study has identified ways in which the nature of an IRE exchange between teacher and students can be altered to promote epistemic discourse by combining the feedback provided in IRE sequences with discursive actions such as ‘Justification’, ‘Prompts for Justification’, ‘Counter-Argument’, ‘Generalisation’, ‘Prompts for Evidence’ and ‘Explanation’.

Transforming the nature of evaluation in IRE patterns through epistemic operations such as prompting for reasons, providing ‘Generalisations’ or ‘Justifications’ would concur with the recommendations made by Kovalainen & Kumpulainen (2005), who argue for a similar transformation and re-conceptualisation of evaluative comments provided by teachers. The re-conceptualisation of evaluation that Kovalainen & Kumpulainen (2005), as well as Wells (1993) mention, is possible if the comments provided by teachers in IRE sequences move from simple feedback to evaluative comments where consideration of the statements by students is made openly and the teachers are either themselves providing a justified judgment to the students’ responses or are inviting students to evaluate and make judgements based on their classmates’ responses and ideas. However, it also needs to be acknowledged that moving away from familiar and ‘safe’ modes of interaction as the IRE pattern is an action by teachers that requires confidence and willingness to change pedagogic perspectives, and an ability to organise and sustain more demanding forms of classroom talk, such as epistemic discourse or argumentation (Driver et al., 2000). Therefore, science teachers need to be introduced and trained not only into *teaching* science through argumentation but also *talking* science through argumentation.

9.2.4 The Development of a 'Grasp of Practice' and 'Accountable Talk' in Science Classrooms

The analysis of classroom talk during the lessons observed as part of the two case studies presented in this thesis, shows how the nature of classroom discourse can take a different form as to be able to address the various epistemic practices of science and not focus solely on the acquisition of factual information (Ford, 2008a, 2008b; McNeil & Pimentel, 2010; Newton & Newton, 2000). Ford (2008b) argues that during science instruction students should be given the opportunity to develop 'a grasp of practice' of the scientific endeavour, which is mainly characterised by the notions of construction and critique/evaluation. What is more, he supports the view that the roles of 'constructor' and 'critiquer' should be undertaken by both the teacher and the students in the science classroom in order to achieve this understanding of science. Ford's argument is based on a commitment to move away from the dominance of declarative knowledge – telling students what to learn or what science is. Instead he argues that students should be presented with, and participate in, activities that can help them develop an understanding of how science works and how scientific knowledge is generated through employing the same reasoning resources that scientists employ in their practices. In this way, students may develop ways of thinking and reasoning that would allow them to be critical of the knowledge they learn at school.

Based on the framework of epistemic operations presented and the consideration of their function for the epistemic practices of science, it has been shown that the dominant epistemic practices presented to students were part of the 'construction' that Ford is arguing for. Both students and teachers were able to take the role of the 'constructor' in their science classrooms. At the same time, the absence of critique from the classroom talk observed was evident. Elements of critique or evaluation were considerably less than elements of constructing knowledge claims in the classroom talk of teacher and students. The cases in which evaluation/critique was found to be present in the teachers' classroom talk was during argument-based instruction. During argumentation lessons, the teachers took up the role of the 'critiquer' and presented to students the evaluative process of knowledge generation, to a greater extent than in non-argumentation lessons. As a consequence, the inclusion of processes of evaluation and critique needs to be emphasised in future research directions and a way to do that, is through considering the practice of argumentation as an instructional approach, as a way to model epistemic evaluation for students.

The use of argumentation as a framework for teaching science facilitated the use of more challenging epistemic operations such as 'Justification', 'Evaluation' and 'Prompts for Argument', 'Prompts for Evaluation' and 'Prompts for Counter-Argument', than merely providing descriptions and information to students. In fact, the two teachers seemed to be moving from less challenging to more challenging epistemic operations. Even so, the sequence of epistemic operations did not always include the use of counter-argument, which is one of the more challenging epistemic operations that teacher and students are asked to participate in during argumentation instruction. Counter-argument is challenging, as it requires the consideration of both for and against positions that an individual has to go through whilst constructing an argument and counter-argument. In this sense, it is not surprising that the two teachers did not place great emphasis on counter-argument, as they were more concerned with helping their students to participate and understand the processes of constructing arguments, before introducing them to counter-arguing.

This practical approach to the implementation of argumentation to the teaching of science demonstrates that when using argumentation in the context of a science classroom, as the two teachers of this study attempted to do, there are a number of elements that need to be taken into consideration. For example, students are most likely not to be aware of ways to argue. Thus, they need to be introduced to reasoning based on the process of argumentation step by step, starting with constructing arguments based on claims and justifications and then move on to evaluation of knowledge claims. Evaluative processes such as 'Prompts for Evaluation', 'Compare & Contrast' and 'Counter-Argument' were mainly used in the lessons observed after the students were introduced or had learnt the content. This would suggest that classroom talk can be organised based on a developmental sequence of epistemic operations, which start from epistemic operations that aim at constructing knowledge claims, to epistemic operations that provide the justification and reasoning that construction is based upon, and finally, to the critique of knowledge claims. This sequence could be used by teachers to help introduce students to more and more challenging discursive activities, providing appropriate support through their prompts or through modelling the talk that they wish their students to engage in during science lessons. Moreover, this developmental sequence of epistemic operations could be utilised in designing activities and prompts such as worksheets that the students could use without the presence of the teacher at the group being necessary for facilitating the use of epistemic discourse by students.

Ford (2008a) also argues that students need to be involved in a dialectic between the processes of construction and critique of knowledge claims, as scientists are. That is, when a claim is constructed and put forward, a process of critical evaluation should also take place, in order to account for possible criticisms from other members of the group. However, as discussed in Section 9.2.2 and shown through the use of discursive actions of the two teachers in this thesis, another aspect that needs to be considered and explicated within the interplay between construction and critique is *justification*. In constructing an argument, the proponent of the argument needs not only to use data to support their claim but also to demonstrate explicitly how that data warrant support to the claim put forward. In this way, justificatory reasoning is demonstrated and the 'epistemic forcefulness' (Siegel, 1995, p.162) of the claim can be established.

Additionally, critique/evaluation is the epistemic practice of considering a claim in comparison to other views or opinions and in light of contradicting or confirming evidence. Such evidence might add to the validity of the claim or undermine it to the degree that needs to be re-structured, qualified or abandoned altogether. In this process of evaluation, justificatory reasoning is employed to demonstrate why one claim is better than another so as to strengthen the judgment made and establish the better argument. For instance, being able to state whether a claim put forward is valid or not, needs an awareness that personal belief through the agreement or disagreement with the statement proposed is not sufficient to convince others of the judgement made. Rather, a justification, which explicitly provides the reasons for or against the statement, is required. Consequently, individuals need to be able, and know how to provide justifications for their beliefs, and this ability should be demonstrated not only in presenting a viewpoint, that is, in constructing a claim, but also when being critical about one's own or other individuals' claims and arguments, that is, in evaluating knowledge claims.

Presenting the justificatory aspect of scientific knowledge production to students is necessary if students are to see the importance of including this element in their talk and of making their reasoning explicit. Making the role of justification explicit in classroom talk through epistemic operations such as 'Justification' and 'Prompts for Justification' could be a way to make the transition from the constructive to the evaluative process in a less cognitively demanding way for the students. That is, if students become accustomed in utilising justificatory comments in their talk whilst constructing knowledge claims, then students could also be more willing and/or able to provide justifications whilst evaluating claims and other students' opinions. As research suggests (and as shown through this study in Chapter 8), students are not accustomed to spontaneously providing justifications for their beliefs (Driver et al., 1996; Sandoval & Millwood, 2005; Sandoval, 2005), which further supports the need to address explicitly the use of justifications as part of the teachers' and students' classroom talk. As Norris (1997) argues:

> 'The important point [of science education] is for students to understand the logic of the reasoning and to grasp, through many examples, the nature of the reasoning used to draw scientific conclusions. They must come to see science as based upon a form of reasoning that they can comprehend, not as a body of facts discerned by some abstruse method' (p.256).

Thus, justification as a practice needs to be addressed explicitly in science education environments if students are to develop this 'habit of mind' and develop the reasoning that Norris (1997) mentions. By promoting the justificatory processes of knowledge production students are participating in talk that is accountable to the reasoning processes of the scientific community (Michaels, O'Connor & Resnick, 2008; Resnick, Michaels, & O'Connor, 2010). In particular this group of researchers has advanced the idea that the talk that characterises not only the teaching of science but all subjects, should be accountable to the community at which that talk is aimed; accountable to the specific reasoning of each discipline; and finally, accountable to the knowledge of that discipline. They justify this view by arguing that:

> 'Opening up the conversation, with interesting and complex problems to support the talk, along with a few key talk moves, gives teachers more access to the thinking, knowledge, and reasoning capabilities of their diverse students' (Michaels et al., 2008, p.287).

The framework of accountability to community, reasoning, and, knowledge within a science learning environment is valuable in describing the ways in which students and teachers may act and interact in the science classroom as to learn science and also learn *about* science. Although these authors provide some extracts from mathematics and science classrooms in which accountable talk is used, their work does not elaborate or explicate how accountable talk can be identified and promoted through the teacher's actions. By utilising epistemic operations such as 'Argument', 'Justification', 'Counter-Argument', 'Compare & Contrast', and prompting students to engage in these discursive actions through 'Prompts for

Argument', 'Prompts for Evaluation', 'Prompts for Justification' and 'Prompts for Comparison' teachers and students *can* develop a discursive practice that is accountable to the reasoning practices of the scientific community through providing justifications and using evidence to support their views. Moreover, through the development of discursive practices that include and promote the epistemic operations mentioned above, accountability to the community can also be achieved since other students' views and opinions would need to be taken into account. Therefore, this thesis has advanced the field by identifying the 'talk moves' that Michaels et al. (2008) mention in the extract above through the epistemic operations identified in the two case studies. Furthermore, through the two case studies, this thesis has provided examples of how the use of these epistemic operations can advance epistemic talk in the science classroom.

9.3 Developing Epistemic Talk in the Science Classroom: The Role of the Teacher's Views of Argumentation as a Scientific Practice and as an Instructional Approach

The second research question of this thesis aimed at identifying aspects of the teachers' talk that changed throughout the school year they were observed teaching, as they attempted to make argumentation part of their everyday practices. Based on the analysis of classroom talk undertaken the two teachers seemed to use argumentation as a distinct approach to their science teaching compared to their everyday teaching practices, as captured through the lesson observations. Moreover, differences between the two teachers were also observed with the teacher of Case Study 1 making more efforts to incorporate argumentation into his everyday teaching practices, as shown by the number and nature of argumentation lessons he taught (Chapter 6). In addition, there was a development of the use of the epistemic operations of 'Justification' (Figure 7.20) and 'Prompts for Evaluation' (Figure 7.22) within the classroom talk of the teacher in Case Study 2 during argumentation lessons. This would suggest that Amy was still developing her skills of teaching and talking based on argumentation and thus, she did not make any attempts to use elements of argumentation into her everyday science teaching.

Through the two case studies, it was established that the way in which the two teachers utilised epistemic operations and formulated their classroom talk was context-specific. In particular, the epistemic operations found in each teacher's talk depended on the type of lesson they were teaching (argumentation or non-argumentation) and within that, on the particular aspects of argumentation that they wished to address. For instance, Lesson 3 in Case Study 1, (an argumentation lesson) focused on selecting from a number of given statements in order to explain the fall of an object. As a consequence, during this lesson, the epistemic operations used the most were 'Justification' and 'Prompts for Justification' as students had to provide a reason for their selection of statements. Moreover, in Case Study 2, Amy seemed to use the epistemic operations of 'Prompts for Evaluation' and 'Prompts for Counter-Argument', in the argumentation lessons she taught as end-of-unit lessons (Lesson 1 and Lesson 5), which provided more opportunities for students to evaluate statements and make comparisons. The link identified between the context of the lessons and the epistemic operations that characterised these lessons is valuable in identifying and promoting those contexts that are potentially more likely to advance epistemic aspects of science. For instance, argumentation lessons as end-of-unit lessons could be used to apply and promote the role of the 'critiquer' (Ford, 2008a, 2008b), since evaluative processes seemed to be more evident in these lessons. Nevertheless, ways in which critique and evaluation can become part of everyday science teaching also need to be explored. Students need to see evaluation and critique as an essential element of the process of knowledge generation if they are to grasp the epistemic nature of scientific knowledge and practices.

Another point to make is that although it was not possible to identify any element of transfer of epistemic features from argumentation to non-argumentation lessons, the consistency with which the two teachers used specific epistemic operations, such as 'Justification', was noteworthy. In particular, the use of 'Justification' was found to be related to the teachers' views of the nature of argumentation in science. For instance, James defined argumentation as the 'ability to justify your viewpoint' and justification was an aspect of argumentation that he seemed to emphasise during informal conversations. The emphasis placed on justification seemed to help James present this aspect of science in a consistent way although his failure to consider other aspects of argumentation, such as evaluation, led to considerably a lesser use of evaluative processes than justificatory processes in his classroom talk. Moreover, Amy's views on argumentation as an instructional approach seemed to influence her teaching and planning of argumentation lessons. In particular, she seemed to be concerned with the use of group work whilst teaching science based on argumentation (personal communication). Her concerns about how well students worked in pairs or groups led her to focus on classroom organisation whilst designing her argumentation lessons. That could be the reason that she tended to teach argumentation as end-of unit lessons, since then students would have learnt all the necessary content and she could focus on having students discussing and debating about the content, rather than constructing their knowledge through argumentation.

As a result, the teachers' views of argumentation, both as a scientific practice and as an instructional approach, appear to have influenced the way they enacted their argumentation lessons and consequently the way they talked during these lessons. Previous findings by Simon et al. (2006), who concluded that the views of argumentation that the teachers participating in their study held influenced their progress in the use of argumentation, also support this finding. As a consequence, in professional development initiatives, such as the T2L project in which the two teachers participated, there is a need to place particular emphasis on developing the teachers' views of argumentation both as a scientific process and as a teaching and learning approach to science. This emphasis should aim to develop the teachers' views of argumentation in a way that is consistent with contemporary perspectives on the use of argument in science and in science education. In this way, teachers could be assisted to improve their instructional practices so as to include various aspects of argumentation such as counter-argument and evaluation, in addition to supporting claims through evidence. Likewise, teachers in pre-service training need to be assisted in transforming their pedagogical views and instructional practices so as to be more conducive to the use of argumentation for learning science, such as by using group work and discussion-based activities (Simon et al., 2006; Zohar, 2008).

Conceptualising argumentation as an epistemic practice places a great challenge on teachers, who have to include in their teaching practices those epistemic discursive operations and epistemic questioning able to advance and support their students' higher-order thinking skills and ability to evaluate critically knowledge claims. Realising what it means to teach argumentation is fundamental for the successful implementation of argumentation in the classroom. Such understanding helps teachers set the appropriate goals and objectives for a lesson and facilitates the planning process. Teachers become aware of the main points they should emphasise to students such as asking them to use several pieces of evidence to support their claims, provide alternative arguments and counter-arguments. What is more, even though teachers may have an adequate understanding of the epistemic nature of argumentation as an approach to science learning, their confidence to teach argumentation could be influenced by their ability to transform their knowledge of argumentation into pedagogically appropriate activities for their students. As Grossman et al. (1989) stress:

> ‘the ability to transform subject matter knowledge requires more than knowledge of the substance and syntax of one’s discipline; it requires knowledge of learners and learning, of curriculum and context, of aims and objectives, of pedagogy’ (p.32).

Therefore, recognition of argumentation as an epistemic practice may not be enough if teachers are not also aware of strategies and heuristics that would enable them to incorporate argumentation in their classrooms. Such was the case of Amy, who as she mentioned in her interviews, had great difficulty planning a lesson based on argumentation (Section 7.2). The two teachers were able to use elements of argumentation such as using data to construct graphs and then interpret that graph to explain a phenomenon. These were activities aligned with their everyday teaching practices, what Shulman (1986) refers to as the teachers’ Pedagogical Content Knowledge or ‘the ways of representing and formulating the subject that make it comprehensible to others’ (Shulman, 1986, p.9). However, elements of teaching based on argumentation such as providing alternatives and engaging students in activities where they have to compare their views and come up with counter-arguments were distinct from the teachers’ everyday science teaching practices or their PCK-base. Consequently, these were aspects of argumentation on which the two teachers placed less emphasis whilst using argumentation as a framework for science teaching. Therefore, science teachers need not only to grasp the underlying epistemic nature of argumentation but are additionally required to embrace the dialogic and interactive aspect of this teaching approach and to be aware of ways in which their understanding of the epistemic and dialogic aspects of argumentation can be presented to their students through designing appropriate activities and developing their argument-based PCK (Zohar, 2008; Zembal-Saul, 2009).

Another parameter that seemed to influence the discursive actions of the two teachers during argument-based instruction was their perceptions of their students’ ability to engage in epistemic discourse. During informal conversations with James either before or after his lessons, he often expressed his concerns about the students’ ability to follow the lessons taught and to stay on-task, especially when having to talk or work in groups (field notes, 1/10/2009, 5/11/2009). Moreover, Amy mentioned during her second interview how she had to take different approaches when using argumentation for teaching low-ability and high(er) ability groups. At Amy's school students were organised on ability grouping or sets, and when she attempted to use argumentation with lower ability sets, she mentioned she had to structure her lessons differently as to lower the level of cognitive challenge and to make it more engaging for the students in the lower sets (A2). Amy also pointed out that students in lower sets were accustomed to putting minimum effort into their group-work discussions and had normative expectations as to the types of activities that their teachers' organised. It seemed that students in lower ability sets were not challenged enough, they were not expecting to be challenged beyond a point, and what is more, often they did not welcome the challenge that argumentation activities might bring. However, Rivard (2004) has found that talk-based activities were able to enhance low-achieving students' learning and comprehension of ecological concepts in his study, more than just writing-based activities. Thus, it is important for teachers to find ways to structure the talk of the science classroom to facilitate student discussion. This study has identified the need to design environments that can be applied with both low and higher achieving students and allow students of all ability levels to develop their thinking and reasoning skills. The framework of epistemic operations and the developmental sequence of epistemic operations discussed in the previous section is a way to address the teachers' concerns and perceptions of their students' ability to engage in argument-based instruction. For instance, teachers could use discursive actions and prompt their students to engage in epistemic talk at various levels, either starting from prompts for evidence and descriptions for lower ability students and move gradually to more challenging discursive actions such as requesting for arguments, justifications and comparisons.

9.4. Students' Use of, and Participation in, Epistemic Talk and their Understanding of Theories and Evidence

The talk and interviews from the group of students from Case Study 1 during the argumentation lessons were analysed to examine what epistemic operations could be identified in the students' talk and their views on the nature and role of theories and evidence in science, so as to provide answers to RQ3 and RQ4. The epistemic operations that students were found using when working in their pairs or groups consisted of providing or taking a position, requesting for evidence/information, justifications or explanations, explanation and justification. The most commonly used epistemic operation was that of taking or proposing a position and providing each other with information, which showed the emphasis of student talk on constructing knowledge claims.

Similar findings of the manner that teachers and students used classroom talk to promote reasoning were reported recently by McNeil and Pimentel (2010). These authors analysed an argumentation-based whole class discussion on climate change in three separate science classrooms and found that making claims and providing evidence dominated the students' discourse. The proportion of classroom talk that focused on reasoning, which was defined as 'justification for why the evidence supports the claim' (p.211) was less than making claims and giving information in two of the three classrooms investigated, findings that are in agreement with the results of this thesis with students' talk in Case Study 1 dominated by providing claims and evidence. As discussed in Chapter 8, the justificatory and evaluative nature of the students' talk paralleled that of their teacher's during the 6 argumentation lessons, whereas their use of epistemic operations to construct knowledge claims had similarities with the classroom talk of their teacher during non-argumentation lessons. Although this is a very small sample of students from the classroom population (4-6 students) working and talking together, the similarity between the students' and their teacher talk is in agreement with previous studies that report that student talk models that of teacher talk in mathematics classrooms (e.g., Webb et al., 2006) and thus, this work helps to strengthen an association between student and teacher talk in the context of science classrooms and argumentation-based instruction.

The students observed as part of this study, seemed to engage in discussion focusing on justification or evaluation when (a) they were confident of their knowledge of the topic discussed (i.e. forces, weight, gravity), as shown by their confidence in using this knowledge and sharing it with the other members of the group; (b) the structure of the argumentation lesson was such that prompted them explicitly to engage in these justificatory or evaluative processes, and, (c) students were provided with opportunities to discuss ideas in pairs and then move on to larger groups. These conditions seemed to be essential in the students' attempts to use epistemic discourse during their group-work. Whilst sharing and comparing results students would prompt for justifications, request evidence and justifications from the pair or students they were sharing with to reach a conclusion, and thus, used epistemic operations that moved beyond asking and providing information/evidence. The findings of the ways the nature of student talk changed depending on the organisational format of the activities has implications for how teachers arrange the learning activities in order to promote epistemic discourse in their classroom. For instance, having students work firstly in pairs and then, in groups of four or six was a common instructional practice of the teacher in Case Study 1 during his argumentation lessons, which provided students with the opportunities to both construct their knowledge and understanding of the concepts discussed and also justify their decisions and evaluate critically other students' ideas and reasoning.

Moreover, an important aspect of the students' epistemic talk during the argumentation lessons observed was their use of the epistemic operations of 'Requests Evaluation' and 'Requests Justification'. These two epistemic operations are an explicit demonstration of the engagement of students with processes of justification and evaluation, since students requested from their peers to provide reasons for a claim or evaluate a statement. These actions have a metacognitive and reflective character and are a sign of 'epistemic thinking' (Mason & Boldrin, 2008). Mason and Boldrin (2008) mention that epistemic thinking is part of metacognitive processes that demonstrate students' ability to reflect on their 'knowing about knowing' (Hofer, 2004), such as 'evaluating information sources, weighing up evidence in support of knowledge claims, integrating contrasting information, [and] reconciling one's own point of view with that of experts' (Mason & Boldrin, 2008, p.380). As a consequence, students, through their use of the discursive actions of 'Requests Evaluation' and 'Requests Justification' whilst participating in argument-based activities, demonstrated higher-order thinking skills and the form of epistemic discourse students should be able to engage in their everyday science learning activities.

Moreover, the examination of the teacher and the student talk during group work provides insights to the teacher-student and student-student interactions during argumentation lessons that have not been investigated before. For instance, McNeil and Pimendel (2010) analysed only small sections of whole-class discussions in science classrooms. Yet, whole-class discussions are not the only classroom configurations that take place in the science classroom, especially when dialogic argumentation is used as a teaching approach. For example, the use of group work is an essential part of the teaching of science as argument since students need to work together to construct their arguments and listen to each other in order to provide counter-arguments and develop their ideas. In contrast to previous analyses of classroom talk such as that provided by McNeil and Pimendel (2010), the analysis of classroom talk presented in this thesis included an examination of three different types of classroom interactions – whole-class, group-work and individual work.

Finally, the students' views of the nature and role of scientific theories and evidence, as explored through interviews within Case Study 1, showed that the four students interviewed had changed their views of facts as the end-point of science to information that can also be used as evidence for or against a viewpoint. The change identified through the student interviews could be attributed to argumentation instruction which would further suggest that the use of argumentation as an approach to science teaching might be a suitable way to help students develop their views of aspects of the nature of science, such as the nature and role of evidence. Students, during argumentation lessons, were prompted by their teacher to use evidence, to provide justifications through evidence and construct arguments. In addition, James often utilised the word 'evidence' in his argumentation and non-argumentation lessons making explicit references to how evidence was to be used to support the students' ideas. Although there was some change into the views of theories as having a predictive nature in addition to theories being ideas or opinions, the students' views of theories did not seem to be influenced and remained stable. Contrary to the teachers' frequent use of the word 'evidence' throughout the 13 lessons observed in Case Study 1, the word 'theory' was not mentioned in the teacher's talk and no explicit discussion of theories as explanations were made during the lessons observed. The total absence of any mention of 'theories' as explanatory frameworks is concerning since as Harré (1984) asserts 'theories are the crown of science, for in them our understanding of the world is expressed' (p.168). Students seemed to respond to their teachers' use of the meta-language of argumentation that he consistently used (such as 'evidence'), which would suggest that if students are to view scientific theories as something more than an idea or speculation then, their teachers should discuss the nature of scientific theories within the science classroom explicitly.

9.5 Limitations of the Study

The findings discussed in this chapter need to be considered along with the context in which this thesis was developed. Throughout the design and implementation of this research project there were some limitations that need to be acknowledged. Firstly, there are methodological limitations based on the case study design of this project. The fact that the sample was based on the two science classrooms reported, means that the findings should be compared with other educational contexts in which argumentation is used. What is more, the extent to which argumentation was implemented in the same way by the two teachers is not fully known. The two teachers participated in the same professional development project, which means they had the same influences by the research team. However, their school environment and the support that they had for using argumentation as part of their teaching practices by their departments might have made it easier or more difficult to implement argumentation. These are issues that were not explored as part of this study. Moreover, it should be noted that although attempts were made to select a representative sample of students for the observations conducted, the results reported are specific to that group of students. Finally, in the analysis and presentation of the results, it is assumed that the non-argumentation lessons observed, that the teachers did not characterise as 'argumentation lessons', were characteristic of their everyday practices. However, the fact that these lessons were observed, might have influenced the extent to which what was taking place during those lessons, were the 'everyday teaching practices' of the two teachers.

9.6 Implications for Future Research

Through this study it has been shown how argumentation as an instructional approach can promote epistemic discourse in the science classroom. These findings further support efforts for promoting and developing pedagogical approaches to the teaching and learning of science based on dialogic argumentation (Duschl & Osborne, 2002; Kuhn, 2005; 2009; Schwarz, 2009; Zembal-Saul, 2009), since the talk during argumentation lessons was more epistemic than in non-argumentation lessons. Schwarz (2009) supports the view that 'argumentative talk emerges generally when structured by the teachers and/or by representational tools' (p.102). In the case of the two teachers of this study, argumentative talk was structured by the teachers through the various prompts identified in their talk, such as 'Prompts for Argument', 'Prompts for Evidence', 'Prompts for Justification' etc. Nevertheless, the existence of a mismatch between the epistemic operations the teachers performed and the epistemic operations they prompted their students to engage in, especially during argumentation lessons, raises questions for the teachers' ability to participate in epistemic discourse.

On the one hand, this mismatch would suggest that the two teachers were aware of issues they had to address during their argumentation lessons and that they attempted to do so through the questions and prompts they addressed their students with. On the other hand, the difference between the epistemic operations they used in their own talk and those they prompted students to use, demonstrates the need for training these teachers into particular ways of using epistemic operations such as 'Argument', 'Evaluation', 'Compare & Contrast' and 'Counter-Argument'.

In the previous sections of this chapter, it has been suggested that future directions for the development of epistemic discourse should focus on both in-service and pre-service teacher training programmes. If students are to develop their use of epistemic discourse, then their teachers need to be able to model that discourse through their own talk (Ford, 2008a, 2008b; Gillies & Khan, 2009; McNeil & Pimentel, 2010; Webb et al., 2006). McNeil and Pimentel (2010) commenting on Ford's notions of construction and critique, state that:

> 'teachers also need to take on the role of critiquer in the classroom community in which they model how to question claims and the justifications for those claims in a manner similar to what they are expecting of their students […] to shift the discourse practices, teachers may need to take on a variety of roles that are unfamiliar to them or not a part of traditional science classrooms' (p.206).

The lack of familiarity with such discourse practices that McNeil and Pimentel (2010) discuss was particularly evident in the talk of the teacher from Case Study 2, as the difference between her prompts during argumentation and non-argumentation lessons illustrates (Figures 7.20 and 7.22). As a consequence, future research into ways of developing argumentation practices in science classrooms needs to introduce teachers to the practice of argumentation and at the same time, help them develop ways of structuring their talk in order to promote epistemic discourse. In particular, professional development programmes focusing on the development of argumentation practices in science education need to present to teachers with the types of activities and discussions their students should be engaging in. What is more, it is important that such professional development initiatives take into account the participating teachers' ability to successfully participate in argument-based discussions and accordingly, provide opportunities for the teachers to develop their own argument-based discursive actions, through proving feedback on the teachers' attempts to teach argumentation lessons and organising workshops where the teachers are themselves participating in argument and counter-argument construction.

Teaching science through argument was able to advance the epistemic discourse of the two science teachers in this study, but the use of epistemic discourse was framed by the teachers' views of argumentation. Thus, professional development programmes and pre-service teacher training courses need to take the teachers' views of argumentation into consideration and help them develop and transform these views into instructional activities. For instance, as mentioned in Section 2.3, Avraamidou and Zembal-Saul's (2005) study provides evidence that pre-service training courses that emphasise the use of argumentation have a positive influence on first-year elementary science teachers' ability to prioritise evidence in their teaching practices. Similar studies need to be developed for secondary school teachers and their ability to use argumentation as part of their teaching practices.

What is more, through examining some of the students' views on the nature and role of theories and evidence in science it was shown that some improvement was noted, especially in the ways in which students' perceived facts as evidence that can support or reject ideas. Nonetheless, this slight improvement cannot be attributed solely to the students' engagement with argumentation activities, as it could be the results of other factors influencing their views about science, which were not accounted for through this study. As a consequence, further research needs to be undertaken to explore how the use of particular epistemic operations in the science classroom may develop students' epistemological understanding. For instance, studies that utilise a control group design might be helpful in making comparisons between the students' views of theories and evidence in argumentation and non-argumentation instruction.

Argumentation engages students in the epistemic process of knowledge production and evaluation, which requires amongst others, the use of evidence choice criteria and evaluation of claims and evidence, persuasion of other members of a group or a class of students and the creation of counter arguments. These are characteristics of science teaching that promote a view of science as an epistemic practice, a view which is different from what students are accustomed today. As Kovalainen and Kumpulainen (2005) stress 'much less is known about student and teacher participation practices in contemporary, interaction-rich classrooms aiming towards collective meaning-making' (p.214). This study by analysing the function of discursive actions in both interaction-rich classrooms, such as the argumentation lessons observed, and more traditional teaching environments as the non-argumentation lessons, has contributed towards the characterisation of classroom talk. Although the data sample is small, the analysis provides an illustration of how the nature of classroom discourse can be transformed from providing declarative knowledge to students, relying on IRE sequences and focusing on content, to a sequence of epistemic operations that advance epistemic discourse in the science classroom and enculturate students into the epistemic practices of science.

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Appendix A

Teacher Interview Schedule

Nature of Science

1.1 What is science?

1.2 What is a scientific theory?

1.3 After scientists have developed a theory, does the theory ever change? If you believe that scientific theories do not change, explain why and defend your answer with examples. If you believe that theories do change: a) Explain why; b) Explain why we bother to teach and learn scientific theories. Defend your answer with examples (from VNOS-B, Lederman et al., 2002).

1.4 What is the role of evidence/facts in science?

1.5 What is the role of scientists within a scientific discipline? Do you think it's important to present to students this [your] view of science?

Beliefs about teaching and learning in science

2.1 How do you think students learn in science?

2.2 What do you think are your best qualities as a science teacher? What are your weaknesses?

2.3 Have you had any experiences/training since you became a teacher, which have help you develop as a teacher? What are these?

2.4 What is effective teaching for you? Can you describe an example of a successful lesson you had with these students? Provide an example of a lesson that wasn't successful with the same class. Why?

Beliefs about argumentation

3.1. What do you think argumentation is?

3.2. What do you think is the value of argumentation for your own development as a science teacher? What is the value for your students' learning?

3.3. Do you think you have used argumentation activities in your classrooms before engaging in the T2L project? How is argumentation different from other ways you teach science?

3.4. Which are the areas that you believe argumentation could be more easily used to teach science?

3.5. Do you enjoy using argumentation to teach science? Do you think your students enjoy argumentation lessons?

3.6 What are the difficulties of implementing argumentation for you and for your students?

APPENDIX B1

Student Interview Schedule

Part A

The aim of the first part of the interview is to elicit students' understanding of theories, evidence and facts and the connection between them.

A1. Climate change activity

We use the climate change activity as an opener for the interview since it is a topic they might be familiar with and thus, more able and willing to talk about. The objective is to give students a familiar context for talking about theories and facts in science.

a. Students read the following statement:

Scientists have found that the Earth's temperature changes over time and they call this *climate change.*

Some people say that this change is because of the increase of carbon dioxide (CO_2) in the Earth's atmosphere.

b. Do you think that the statement in the box is a 'theory' or a 'fact'?

If students respond **FACT**

- **Why do you think that this is a fact?**
- **What do you mean by the word 'fact'?**
- **Can you give me some more examples of facts?**
- **Do you think we use facts in science? If yes, then how?**

- **If this is a fact, then what is a theory?**
- **Can you give me an example of a theory?**
- **Do you think we use theories in science? If yes, then how?**

Then ask

- **Do you think there is a connection between facts and theories?**
- **Which one do you think is more important? A theory or a fact? Why?**

If students respond **THEORY**

- **Why do you think that this is a theory?**
- **What do you mean by the word 'theory'?**
- **Can you give me some more examples of theories?**
- **Do you think we use theories in science? If yes, then how?**

- **If this is a theory, then what is a fact?**
- **Can you give me an example of a fact?**
- **Do you think we use facts in science? If yes, then how?**

Then ask:

- **Do you think there is a connection between facts and theories?**
- **Which one do you think is more important? A theory or a fact? Why?**

A2. How certain are scientists?

Students are presented with the following statements and are asked to consider whether they agree/disagree with them and explain why.

a) Scientists are very certain about how the Earth looks like from space
b) Scientists are very certain about the way that dinosaurs looked like
c) Scientists are very certain about the way the Earth was created

- If they are not certain about some of these things/statements, then how can scientists be more certain? What is the role of evidence in this process?
- Can scientists ever be [absolutely] certain?

Part B: Coordination of theory and evidence

The aim of the second part of the interview is to identify students' ability to coordinate theory and evidence. Coordination of theory and evidence includes the consideration of how different pieces of evidence can be consistent or inconsistent with a particular theory.

B1. Why is the Earth round?

Students are given the statement in the box, which the interviewer presents in a statement and reads for the students. Then, statements/evidence 1-5 are presented to the students, who are asked to consider each piece of evidence and order them from the most convincing/strong piece of evidence to the least convincing/weakest piece of evidence. Students are asked to justify their selections at each stage of the activity.

Almost everyone in the world today, believes that the Earth is round like a very large ball.

Which statement (1-5) do you think is the best reason to support the statement in the box?

1. They have seen pictures and videos from satellites
2. It is in our science textbooks, so it must be true.
3. The scientists that went to space told everyone that's the way it is.
4. Because the Moon and other planets are round.
5. Because sailors can travel around the Earth with their ships and will never fall from the edge of the Earth.

B2. How we see things!

Students are presented with two competing theories about light and are asked to choose which idea they think is the best and justify their selection. Then, students are presented with evidence cards and are asked to consider whether each piece of evidence supports, rejects or is irrelevant to the theory they chose as the best.

a. Show students the two theories. Read the theories to the students, if necessary (especially for Year 9s) and provide any clarifications they need.

Theory 1

Light rays travel from our eyes onto the objects and enable us to see them.

Theory 2

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

b. Ask: **Which theory do you think it's the best?**

Why?

c. Show students the following evidence statements, **one by one**.

A. Light travels in straight lines

D. We can see things during the night

E. We wear sunglasses to protect our eyes

For each statement ask:

- **Does it support, reject or is it irrelevant to your theory?**
- **Why?**

IF students have difficulty with statements A, D, E (they do not understand them or are not able to explain them), then show them statement B, which is easier to understand.

B. If there is no light we cannot see anything

B3. Floating and Sinking

This task aims to identify students' ability to coordinate theories and evidence by considering students' criteria for theory selection (empirical evidence, external authority-teachers, books, familiarity with sinking and floating) and students' ability to explain confirming and disconfirming evidence. Another aim is to look at students' reactions to anomalous data and their ability to evaluate theories in the light of anomalous data.

a. Show students the three theories about sinking and floating. Read the theories to the students, if necessary (especially for Year 9s), and provide any clarifications they need.

Theory 1

Things that are light float and things that are heavy sink.

Theory 2

Things float if they contain air. If they don't contain any air, they will sink.

Theory 3

Some materials float and anything made of them floats. Other materials sink and anything made of them sinks. The material an object is made from is all that matters.

b. Ask: **Which theory do you think it's the best?**

Why?

IF students do not mention why they think the other two theories are not good enough

Ask: **Why isn't Theory (1,2,3) good enough?**

IF students cannot decide which theory to choose (usually they are between two theories) suggest: **Let's go with Theory [] and try to make some predictions.**

c. Based on the theory that students choose as the best, **ask them to make some predictions.**

IF students choose **Theory 1** ask

- What will happen to…

2 confirming evidence

…**a toy boat** (light/floats)

…**a real car** (heavy/sinks)

2 disconfirming evidence

…**a sheet of cooking foil** (light/sinks)

…**a small marble** (light/sinks)

IF students choose **Theory 2** ask

- What will happen to…

2 confirming evidence

…a glass bottle (contains air/floats)

…glass marble (no air/sinks)

2 disconfirming evidence

…a piece of wood (no air/floats)

… candles (no air/float)

IF students choose **Theory 3** ask

- What will happen to…

2 confirming evidence

… a small and a big glass marble (same material/both sink)

… stones of different sizes (same material/sink)

2 disconfirming evidence (in this case the 2 pieces of evidence are presented together)

… glass bottle floats

…glass marbles sink

For each piece of evidence:

1. Students are asked to make a prediction

2. The interviewer shows the image of what really happens

3. The interviewer asks**: Does this [the evidence] support or reject your theory?**

After students make their predictions and explain the four pieces of evidence presented to them, ask:

- **What does this mean for you theory?**

IF students recognise conflict and change their theory with one of the other two theories then present a disconfirming evidence for that theory. For example, if students change from Theory 2 to Theory 3, ask them to consider why a glass marble sinks and a glass bottle floats if they are made out of the same material.

C. Scientists' work

This question aims at making students consider how scientists would use theories and facts in science and to talk about what they think scientists do.

- ➔ Do you think that what we just did here today has any similarities or differences to what scientists do when they are doing science?
- ➔ What are these similarities/differences?

APPENDIX B2

Student Interview Coding Framework

Formal Epistemologies

Climate change statement
Climate change is a fact
Climate change is a theory

Conceptions of Facts
Examples of facts
Facts are true/proven
Facts are used as evidence
'We learn facts'

Conceptions of Theories
Examples of theories
Theories are tentative ideas/opinions
Theories are used to predict
Theories are used to explain

Links between theories, evidence and facts
Theories create facts
Evidence supports theories
Theories are tested through experimentation
Theories more important than Facts
Facts more important than Theories
Both are equally important
Proven theories become facts
Facts create Theories

Source of Knowledge in Science
Scientists' work
Concept of evidence
Notion of proof
Views on argumentation
Tentative science

Practical Epistemologies

Coordination of Theory and Evidence

1. Theory Selection
'How we see things': Theory 1
'How we see things': Theory 2
'Floating & Sinking': Theory 1
'Floating & Sinking': Theory 2
'Floating & Sinking': Theory 3

2. Justifications of theory selection
Explain Evidence
Use Evidence
- use of direct evidence
- Use of indirect evidence
- Inappropriate use of evidence

Justifications Other than Evidence
Familiarity with Phenomenon
Use of Several Theories
No Explanation

3. Dealing with conflicting data
Recognize conflict
Accommodate Evidence
Change Theory
Maintain Theory
Qualify Theory
Reject All_Create New theory

APPENDIX B3

A comparative account of the interviews of S3, Case Study 1

S3, Year 9	Interview 1	Interview 2	Comments on Change
Climate change	Theory-‘some people say’, it’s not being experimented or checked on	Theory-‘some people say’ It’s not been proven	No change-same justification provided
Facts	100% sure It’s being researched and experimented on You can expand on them but not change them, they are certain	Facts are proven and investigated You use facts by trying to develop and extend them, adapt them if necessary	No change
Theory	An opinion that has not been tested or experimented yet	An idea/opinion about what might happen Theory as prediction They are investigated to see if they are true or not-theory as prediction	Idea of theory is more complex, not just ‘a tentative idea’
Evidence	Evidence backs up theories which can then be made into facts through testing	Theories are tested and the evidence from the testing is used to back up the theory Evidence backs up both theories and facts because facts were once theories	Same - Evidence back up theories - Evidence is obtained through experimentation and testing - Some elaboration on how evidence supports an idea in the second interview
Fact v. theory	Equally important because you need to find out people’s views Theories are tested and if true they become facts	Equally important because you need a theory to make a fact Theories are tested and if true they become facts	He is placing greater emphasis on testing and proving in his second interview

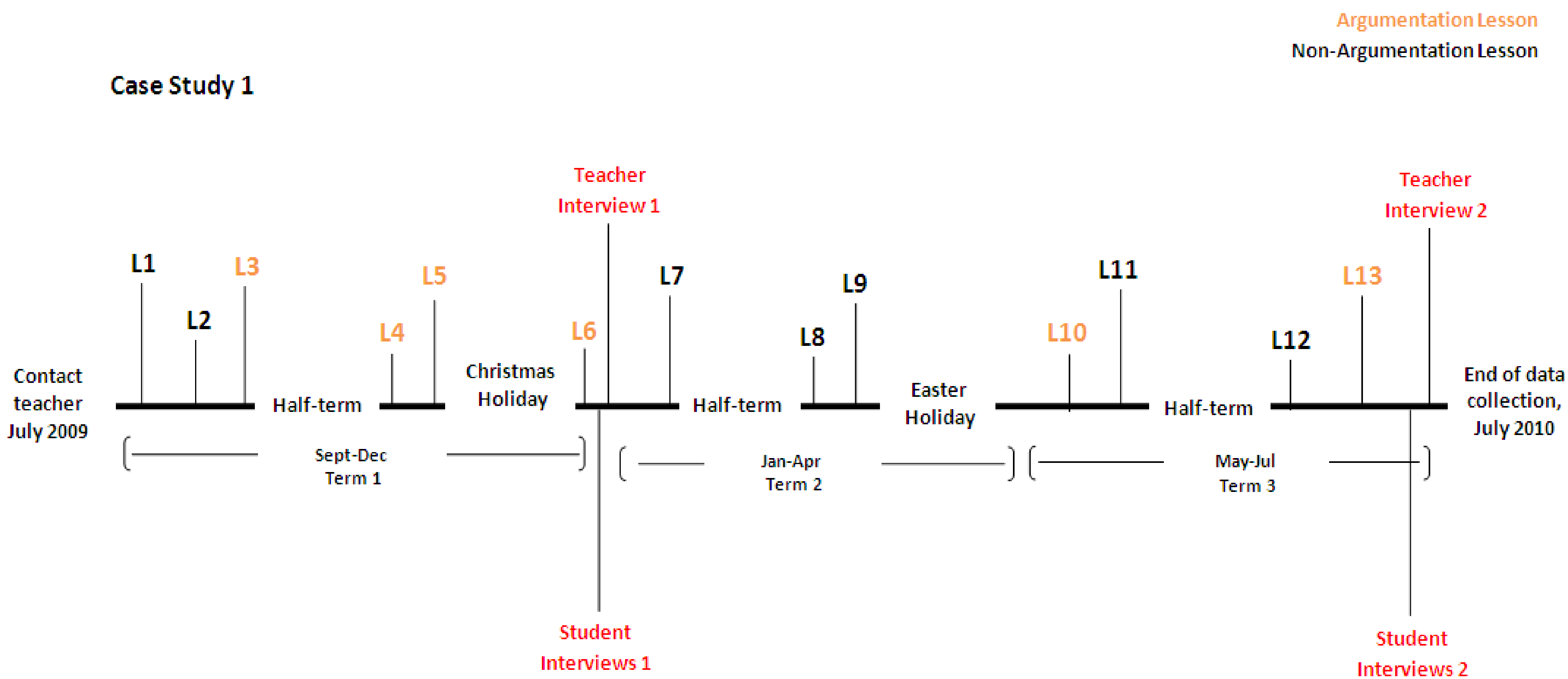
	Interview 1	Interview 2	Comments on Change
How we see things	Theory 2-Phamiliarity with phenomenon used as justification-he restates the theory. Use of E2.4 and E2.6 when prompted	Theory 2-Phamiliarity with phenomenon-use of evidence to reject theory 1 when prompted ‘we wouldn’t need the sun or light bulbs’	Reasoning improves-coordination of theory and evidence is better-he can give reasons why not.
Light travels in straight lines	E.2.4 and E2.6 to explain the evidence	Explains Evidence as supporting because of lights rays coming into eyes	C.Theory& Evidence better, he can use the theory to explain the evidence but he still can’t see how it can go both ways
We can see things during the night	Explains evidence when there is a source of light; use of E2.4 to explain when its pitch black but he eventually uses E2.1 and rejects theory 1 ‘if you cant see anything in pitch black it means there’s no lighting coming out of your eyes’	Uses the presence of not of a source of light to explain the evidence	same
We wear sunglasses to protect our eyes	Use of E2.1 to explain evidence	Use of E2.1 to explain evidence He also explains why it’s not theory 1 based on the statement	C. Theory and Evidence is better, he gives more reasons for the statement to support Theory 2.
What scientists know	a, b, c	a, b, c	From the use of direct evidence towards the use of experimentation and testing for making sure-implicit use of evidence to support an answer is shown through his reasoning

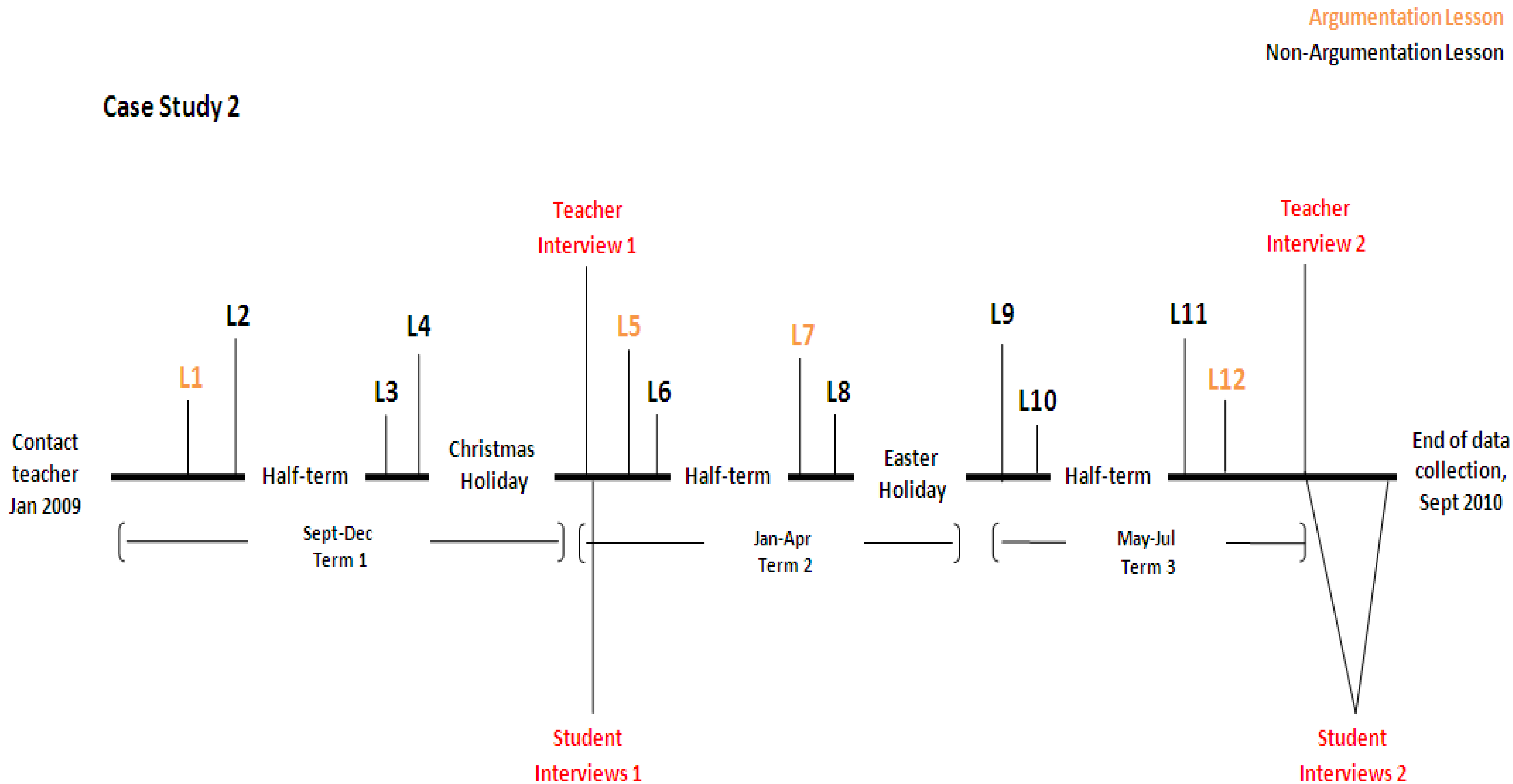
	Interview 1	Interview 2	Comments on Change
a. How the earth looks like	Direct evidence, people have being to space	Direct evidence-people being into space and have seen the earth	same
b. How the dinosaurs looked like	Use of fossils-indirect evidence, scientists have 'enough' evidence	Use of fossils-further experimentation can make scientists sure about B but not about C	Places more emphasis on experimentation for becoming certain and use of evidence
c. How the earth was created	Not true, no way to know because there is nobody to tell them-use of direct evidence, 'scientists don't have much evidence'	There is no evidence proven to say that and there are many theories about it like the Big Bang but most of the theories you can't have experiments on You need people or technology to say how it was created	Moves from the use of direct evidence to the use of experiments for making sure and which in this case is not possible because there are no suitable experiments to do.
'Earth is round'	Direct evidence-taking pictures Indirect evidence: rotation on axis would be different, day and night would be 'weird' and seasons 'would be all wrong'	Direct evidence-people have taken pictures of the earth from space	
Evaluating the quality of evidence	D, E, B, C, A Places emphasis on direct experience and evidence and also on authority from scientists and textbooks. Statements with indirect evidence are last, C because of inductive reasoning-doesn't mean all are like that and A because of gravity-they wouldn't fall anyway	D, B, E, C, A. Direct experience is the most important-D above B because the pictures are better than the scientists saying so; A is not true because of gravity and C not good enough based on inductive reasoning.	Same-there is a slight preference to direct evidence in the second interview.

	Interview 1	Interview 2	Comments on Change
Sinking and Floating	Theory 2: gives confirming evidence Gives evidence against theory 1 E2.6 for theory 3	Theory 2: rejects Theory 1 and Theory 3 using evidence Supports Theory 2 through evidence-glass bottle floats	Better use of evidence to support his selection of Theory 2, using examples why not for 1 and 3 **Improvement on use of evidence**
Use of Evidence	Explains all predictions/evidence presented to him successfully (E2.1 and E.2.2)	Explains all predictions (E2.1 and E2.2) No E2.6 used-he is always using evidence to support his answers	**Improvement on explaining** evidence-coordination of theory and evidence is done with focusing on providing evidence instead of other ways of justification
Conflicting data	Recognises conflict and uses Multiple theories at the end (maintains Theory 2 but also Theory 3 for different pieces of evidence)	Recognising conflict, accommodates conflicting evidence (candles contain air) and qualifies theory to account for conflicting data (wood floats).	Ability to consider how a theory can be modified to accommodate disconfirming evidence instead of using multiple theories: **Improvement**
Tentative science	There are always new ways to find things out-through technology Scientists can be certain but not extremely certain He talks more about changing as in accumulation or modification of knowledge rather than rejection in light of new evidence	Scientists can't know for sure for things like how the earth was created because there is nobody from the past but can know for sure for other things.	No change
Scientists' work	Lots of 'scientists do experiments' They have theories which they test and use evidence to see which theory is correct. They will use much more evidence than in the interview	Scientist s find theories and experiment with them to decide **which one works the most**	Becomes more evaluative also shown from his views of what science is.

	Interview 1	Interview 2	Comments on Change
'What is science'	Likes doing experiments Sees the relevance of some things he learns in science but not others 'learning about pesticides not important because I wont become a farmer' 'Science is about experimenting and finding out new things all the time' 'if one thing does that would that mean another thing does this': predictive power of scientific knowledge/theories	They don't do much experimenting like scientists, they mostly work from textbooks. Science is 'finding new ways of how things work and which is the best solution to stuff'	Moves from a view of science as experimentation towards an understanding of science as how things work and finding the best solution to stuff' **Improvement**
Working in groups-discussions in science	Likes group-work 'Because then, I think that the discussion helps me. Because like if I am by myself and I don't understand it it's hard for me but if there is someone else to help me then I find that easier.	I: Do you like the lessons that you do groups and talk together? S3: Yeah. I: Yeah? Why do you like that? S3: Because like, it's more of a collective idea and then you can put your own ideas together and work from that. With group-work you get other people's ideas which might help you learn	
Views on argumentation	Argumentation is like debate Say why you disagree with someone's opinion	Argumentation is ways to support something and also go against it,' to ding more to adapt the answers and conclusions'	A more evaluative stance is present in the second interview on adapting answers, it's important for people to state their views. **Improvement**

APPENDIX C


Argumentation Lesson
Non-Argumentation Lesson
Case Study 1
Teacher Interview 1
Teacher Interview 2
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
Contact teacher July 2009
Half-term
Christmas Holiday
Half-term
Easter Holiday
Half-term
End of data collection, July 2010
Sept-Dec Term 1
Jan-Apr Term 2
May-Jul Term 3
Student Interviews 1
Student Interviews 2


Argumentation Lesson
Non-Argumentation Lesson
Case Study 2
Teacher
Interview 1
Teacher
Interview 2
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
Contact
teacher
Jan 2009
Half-term
Christmas
Holiday
Half-term
Easter
Holiday
Half-term
End of data
collection,
Sept 2010
Sept-Dec
Term 1
Jan-Apr
Term 2
May-Jul
Term 3
Student
Interviews 1
Student
Interviews 2

APPENDIX D1

Epistemic operations identified in the teacher's talk

Teacher-*performed* Epistemic Operations	Teacher-*Prompted* Epistemic Operations
Analogies & Metaphors	
Argument	Prompts for Argument
	Prompts for Classification
Compare and Contrast	Prompts for Comparison
Counter-Argument	Prompts for Counter-Argument
Definition	Prompts for Definition
Description	Prompts for Description
Evaluation	Prompts for Evaluation
- IRE	
Exemplification	
Explanation	
Generalisation	
Justification	Prompts for Justification
- Procedural	
- Reflective	
- Content-based	
- 'Why' questions	
Modelling	Prompts for Modelling
Prediction	Prompts for Prediction
Provides Information/Evidence	Prompts for Evidence

APPENDIX D2

Coding categories identified in student talk

1. Analogy
2. Argument
3. Compare &Contrast
4. Counter-position
5. Definition
6. Description
7. Evaluation
8. Exemplification
9. Explanation
10. Generalisation
11. Prediction/Guess
12. Proposing position
13. Provides Information/Evidence
14. Provides justification
15. Requests clarification
16. Requests evaluation
17. Requests Information/Evidence
18. Requests explanation
19. Requests Justification
20. Takes position

APPENDIX E

An example of the structure of students' talk transcripts

Lesson 6 (observed January 14th, 2010), Argumentation Lesson, Case Study 1

Written on the board (before students enter the room):

DDT
BIO-ACCUMULATION
TARGET ORGANISM
BIOLOGICAL CONTROL

ARE PESTICIDES A PROBLEM?

ARGUMENT: - YOUR VIEWPOINT
+ JUSTIFICATION (EVIDENCE)

COUNTER-
ARGUMENT : JUSTIFICATION FOR NOT HOLDING OTHER VIEWPOINT
(RUBISHING THE OTHER VIEWPOINT BUT DOING IT
USING EVIDENCE)

He stands at the door and gives students a sheet with the information on DDT titled Pesticides: trace the poison. The have to start working on it until all students get to the room.
[1.20] He comes in and has a look around the groups and what they are doing until the rest of the students arrive.
[3.13] The teacher gets in and goes to his desk

Teacher talk	Pair 1 talk (Girls) + Group talk	Pair 2 talk (Boys)
0:03.1 - 0:08.1 **117** Do your job guys. [works on his computer; students talk] Guys can you do what it says on the sheet? **118** S5: Oooh... **119** Teacher: Oooh. **120** [Students laugh] **121** S5: Normally you write it on the board sir. **122** Teacher: Just do it quickly as a starter. **123** S5: [inaudible] **124** Teacher: It's a starter. **125** [Gets up and goes to group A; explains them what to do-he doesn't have the microphone on until 4.41 so the sound is not clear] **126** [Goes to group B] OK? You know what to do? [Has a look and goes to group D] **127** Teacher: Today I would like you to do exactly what you've been asked to do. **128** S6: Yes sir, you have to do black dots. **129** Teacher: Don't tell me, just do it. **130** [To S7] OK, so what you've got to do is count the black dots, count the aphids, divide the black dots amongst the aphids, so draw the black dots on the aphids and then…	[S1 is at her seat but S2 is not in yet] [S1 starts reading the sheet] [S8 comes in and sits with S1] S8: Oh, we've done this with Mrs. Williams. S1: Yeah. S8: We have to do this? S1: Yeah. S8: OK. Divide the number of black dots…[reads instructions] That dots…and that… Teacher: OK? You know what to do? S1: Oh, I get it. You have to, there's 18 and you have to divide it by how many of these [aphids] S8 1, 2, 3, 4, 5, 6, 7, [counts the aphids] 18. S1: Oh, 1. [S2 comes to the table] S1: Yeah, just write one. S8: "Do the same with the blue tits and the owl'. 3 divided by one? So it's 3. S1: Yeah.	[S3 and S4 take their places. S9 is sitting with them] [S4 reads the sheet] S4: OK. Sir, do we actually do it? Teacher: Yeah. [boys start working on the activity] S9: So basically you have o divide the number of black dots by the number of the aphids. [S4 does the activity; S3 is watching]

APPENDIX F

Student and Parents Consent forms and Information Sheets

KING'S College LONDON

University of London

PARENT INFORMATION SHEET

REC Protocol Number: **REP(EM)/08/09-48**

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of study: Features of science teachers' classroom talk *about* science and their influence to students' understanding of the nature of science[13]

Dear Sir/Madam,

I would like to ask for permission for your child to participate in this postgraduate research project. You should only allow your child to participate if you want to; choosing not to will not disadvantage him/her in any way. Before you decide whether to give permission, it is important for you to understand why the research is being done and what your child's participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

This research project is part of the project regarding the implementation of argumentation in science lessons, which your child is already participating. The aim of this research project is to explore the ways that science teachers talk about science when they are doing argumentation activities with their students. Moreover, science teachers' talk during argumentation will be compared with the talking that takes place during ordinary science lessons (where the focus is not on argumentation activities). This comparison can help us find if, and how, students are influenced by the different ways their science teachers talk about science. Your child's participation in this project will be valuable when attempting to see how the talk that takes place in science classrooms is understood by students and how it influences their conceptions of the epistemology of science. This research project could determine the features of science teachers' talk that help students understand science better.

---

[13] This was the initial title of the study

This research will require a small group of students of three different classrooms to participate in an interview that focuses on students' ideas of the nature of science. Moreover, I would like to follow this group of students and record their discussions in the science lessons observed. Whole class video-recordings of ordinary science lessons focusing on the teacher will also be collected. Your child's teacher is informed and willing to participate in the project.

I would like to assure you that your child will not be exposed to any kind of risks during the project and all necessary measures will be provided for anonymity and confidentiality. The interviews will be audio recorded but only the participating researchers will listen to the recordings of the interviews and know which child provided each answer. Moreover, the videos from the classroom observations will not be shown to anyone besides the participating researchers. Written examples from the interviews may be shared with other researchers, but your child will be completely anonymous. Only the researcher will be able to connect the data to your child's school. Your child's name will also be removed from any samples of their work.

If you wish further information please contact me via email andri.christodoulou@kcl.ac.uk.

It is up to you to decide whether to allow your child to participate or not. If you decide to consent to your child participating please keep this information sheet and sign the consent form provided. Keep in mind that if you decide to give permission, your child is still free to withdraw from the project without giving a reason approximately until April 2010 that the data collection process is to be completed.

Finally, if this study has harmed you in any way you can contact King's College London using the details below for further advice and information:

Peter Kutnick
Department of Education and Professional Studies
King's College London
Rm 1/14
Franklin-Wilkins Building
London SE1 9NH

0207 8484420
peter.kutnick@kcl.ac.uk

PARENT CONSENT FORM

Please complete this form after you have read the Information Sheet explaining this research project.

KING'S College LONDON

University of London

Title of Study: Features of science teachers' classroom talk *about* science and their influence on students' understanding of the nature of science

King's College Research Ethics Committee Ref: REP(EM)/08/09-48

Dear Sir/Madam,

Thank you for considering allowing your child to participate in this research. The information sheet accompanying this consent form includes all the information relating to the project. However, if you have any questions arising from that, please do not hesitate to ask the researcher (Andri Christodoulou) before you decide whether to give consent. You will be given a copy of this Consent Form to keep and refer to at any time. Please note that confidentiality and anonymity will be maintained and it will not be possible to identify your child from any publications.

I understand that if I or my child decides at any time during the research that no longer wishes to participate in this project, I or my child can notify the researchers involved and my child will be withdrawn from it immediately.

I consent to the processing of my child's personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Guardian's Statement:

I ____

agree that the research project named above has been explained to me to my satisfaction and I agree to let my child ____take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Please circle your relationship to the child named above:

Father Mother Guardian Other …………………….

Signed________________________________ Date______________

Please return this consent form to your child's science teacher. Thank you!

STUDENT INFORMATION SHEET

KING'S College LONDON
University of London

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

King's College Research Ethics Committee Ref: REP(EM)/08/09-48

Title of Study: Features of science teachers' classroom *talk about* science *and* their influence to students' understanding of the nature of science

Dear student,

I would like to ask you to take part in my research project. Please read this information leaflet before you decide. You should only accept to take part if you want to; choosing not to will not disadvantage you in any way. Before you decide whether to give permission, it is important for you to understand why the research is being done and what you will have to do. Please take time to read the following information carefully and discuss it with others if you wish. Ask me or your science teacher if there is anything that is not clear or if you would like more information.

This is what I want to do:

This project aims to explore the ways your science teachers talk about science when they are teaching you. By doing this we can find ways of helping you learn science better.

To do that, I will be coming into your classroom and will video-record some of your science lessons. These videos will focus on your teacher. I would also like to interview some of you. During this interview I will ask you some questions about science and science learning. Finally, I would like to audio-record some of you as you talk during your group work.

Your science teachers have also agreed to participate in the project.

None of the information I collect will be given to your teachers and you will not be assessed on the answers you provide. Your name will be removed from any samples of work I might use. The videos from your science lessons will not be shown to anyone besides the participating researchers. If you would like more information, please contact the researcher Andri Christodoulou (andri.christodoulou@kcl.ac.uk). Keep in mind that if you decide to give permission, you are still free to withdraw from the project until July 2010 that the data collection process is to be completed.

If you do agree to this, I need you to sign the form beneath.

Finally, King’s College operates a no-fault compensation scheme for all its research so if this study has harmed you in any way you can contact King's College London using the details below for further advice and information:

Peter Kutnick
Department of Education and Professional Studies
King's College London
Room 1/14
Franklin-Wilkins Building
London SE1 9NH
0207 8484420
peter.kutnick@kcl.ac.uk

STUDENT CONSENT FORM

Please complete this form after you have read the Information Sheet and listened to an explanation about the research.

Title of Study: Features of science teachers' classroom talk *about* science and their influence to students' understanding of the nature of science

King's College Research Ethics Committee Ref: REP(EM)/08/09-48

Dear student,
Thank you for considering taking part in this project. If you have any questions arising from the Information Sheet or the explanation already given to you, please ask the researcher or your science teacher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

- ***I understand that if I decide at any other time during the research that I no longer wish to participate in this project, I can notify the researchers involved and be withdrawn from it immediately without giving any reason. Furthermore, I understand that I will be able to withdraw my data up to the point of publication or up until the point stated on the Information Sheet.***
- ***I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be treated in accordance with the terms of the Data Protection Act 1998.***

Participant's Statement:

I ____

agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Full name (in capitals): ____

Signed________________________________ **Date**______________

Please return this form to your science teacher.
Thank you!

APPENDIX G

Case study 1

A description of the affordances for epistemic talk of each lesson observed

Lesson 1

How do we know smoking is bad for you?

This was a health-related lesson on smoking and its consequences. As James stated to the students the aim of the lesson was ‘to look at how we discovered in fact tobacco is not very good for you at all’. The first activity students were asked to undertake was to talk in pairs about a 1950s advertisement portraying a woman smoking projected on the board, while James took the register. Then, in whole class, James asked a series of questions based on a graph given to students. The discussion about nicotine levels included how often a person would need to smoke a cigarette based on the graph provided and how many cigarettes that person would need to smoke in a day. The next activity focused on question 1b (The graph below shows the amount of nicotine in cigarettes has changed between 1930 and 1990. Predict one consequence of reducing the amount of nicotine in cigarettes) of the worksheet students were given as they entered the classroom. The main activity of the lesson required students to draw a graph based on a set of data provided to show the percentage of males and females smoking from 1948 to 2006.

In addition, the lesson included a demonstration by James of a cigarette burning and the by-products of that, as part of his attempt to answer the question: Why has smoking become less popular over the years? This was the conclusion students drew from the graph they were asked to draw in the previous activity. The presence of procedural talk would be expected due the demonstration that he made to the students. As the lesson was carried out issues related to the language of science (What is correlation? What is the difference between transparent and translucent?), and skills such as noticing, observation, and precision, were discussed by James and the students during the demonstration.

After the lesson, James mentioned that he had originally planned this lesson as a 'talk-about data/evidence' but because of time restrictions he was not able to gather the information he wanted students to use. Instead he gave them a different set of data as mentioned above, and asked them to plot the graph and draw conclusions from it. Although this lesson was not characterised by James as an argumentation lesson, there were opportunities for students to work in pairs or groups and talk about their ideas. In particular, part of the objectives of the lesson was for students to practice and develop skills or 'good habits' as he wrote on the board. Throughout the lesson, he had a column written on the board named 'Good habits' and under that he had listed: asking questions, reflecting ideas, making links, negotiating, persuading. For this reason, this lesson provided the teacher and students opportunities for the use of epistemic operations such as Explanation, Argument, Prompts for Argument, Compare & Contrast and Prompts for Comparison. As shown from the analysis, Lesson 1 had the most instances of 'Argument' found in the teacher's talk from all the non-argumentation lessons observed (Appendix H).

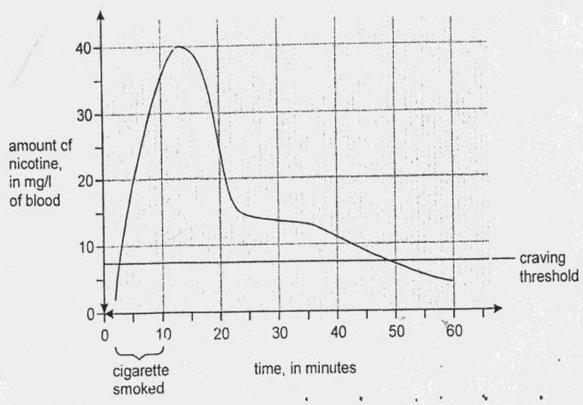
Data students had to use to produce a graph during Lesson 1

Percentage of the adults who smoke		
	Men	Women
1948	65	41
1952	59	38
1956	61	41
1960	61	42
1964	54	41
1970	55	44
1974	51	41
1978	45	37
1982	38	33
1986	35	31
1990	31	29
1994	28	26
1998	30	26
2002	27	25
2006	23	21

02, B2, 12

1. Wesley wants to give up smoking but finds it difficult.

(a) The graph shows the level of nicotine in Wesley's blood after he smokes a cigarette.
The craving threshold is the amount of nicotine he needs in his blood to stop him wanting a cigarette.



(i) Use the graph to calculate how often Wesley needs to smoke a cigarette to keep the nicotine level above the craving threshold.

....

1 mark

(ii) Wesley continues to smoke often. His craving threshold goes up. Explain why this happens.

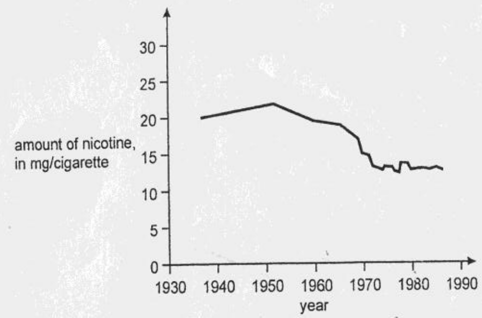
....

....

1 mark

02.B2.12

(b) The graph below shows how the amount of nicotine in cigarettes changed between 1930 and 1990.



Predict **one** consequence of reducing the amount of nicotine in cigarettes
Give the reason for your answer.

....

....

....

....

2 marks

(c) Cigarette smoke contains carbon monoxide. If a pregnant woman inhales cigarette smoke, some of the red blood cells will combine strongly with carbon monoxide instead of oxygen.

If a pregnant woman smokes, how could this harm the foetus?

....

....

1 mark

Maximum 5 marks

1. (a) When tobacco is burned in cigarettes, carbon monoxide is formed.
A device called a 'Smokerlyzer' measures the percentage of carbon monoxide in a person's breath. This indicates the percentage of carbon monoxide in the person's blood.

Four people tested their breath using a 'Smokerlyzer' as shown below.
They repeated the test every two hours during one day at work.

Smokerlyzer™ Bedfont Scientific Ltd

The results are shown in the table.

name	percentage of carbon monoxide in the blood			
	9 am	11 am	1 pm	3 pm
Amy	3.6	2.9	3.4	2.8
Don	1.8	1.3	1.2	1.2
Kisham	6.3	5.0	4.3	3.8
Pat	0.5	0.3	0.3	0.3

(i) Look at the table above.
Which **two** people are most likely to have smoked tobacco before 9 am?

.... and ....

1 mark

(ii) Don says he is a **non**-smoker. Suggest **one** other way carbon monoxide could have got into Don's blood before he came to work that day.

....

....

1 mark

(b) Red blood cells transport oxygen from the lungs to the muscles.
If the air we breathe in contains carbon monoxide, the red blood cells will take up carbon monoxide instead of oxygen.

Use this information to explain why, when they are running, many smokers become out of breath sooner than **non**-smokers do.

....

....

....

....

2 marks

Maximum 4 marks

Lesson 2

Surface area Vs. Weight

This was a non-argumentation lesson focusing on the relationship between weight and surface area. This lesson was the only observation that took place in an English classroom and not the usual science lab that James was teaching in. Students were organised in groups of 4-6 and were given scales where they had to measure their weight, calculate their mass and then using graph paper, determine the ratio between weight and surface area. The first activity involved students in their groups thinking and talking about the questions James had on the board as the students came in the room. A cube was projected on the board, with the following instructions and questions: 'Here is a cube, sitting on a table. *Q1: Are there any forces acting on the cube? Q2: If so, where are they acting? Q3: How could you calculate the surface area of the cube?'.* The discussion activity lasted for about 3 minutes after which James, in whole class, asked students from different groups to share their answers for Q1 and Q2, modelled the forces acting on the cube using force diagrams, emphasised that 'weight is a force that acts down', and then talked them through the mathematical formula that would calculate the surface area of a cube. The objective of the main activity of this lesson as James stated to the students was to 'work out the pressure that you put on the floor when you stand up'. He gave them graph paper, scales and asked them to work in groups to figure out how they could calculate that pressure. Students worked in groups for about 10 minutes after which James started a whole-class discussion where he evaluated the students' work up to that point and then gave them further information on how to proceed to calculate pressure. At the end of the lesson, he showed students a picture of a man sharping and knife and asked them to use what they had learnt about pressure in order to explain why he was sharping the knife.

The specific affordances for epistemic discourse during this lesson were present particularly in terms of justification and discussion of evidence, as students were asked to gather data and through their investigation, establish the relationship between weight and surface area. The potential for higher-order epistemic operations was especially present during the last section of this lesson where James discussed everyday applications of the relationship discussed during the lesson. During this part of the lesson he utilised the epistemic operations of ‘Explanation’ and ‘Justification’ and he also prompted students to provide justifications and explanations of how the relationship discussed during the lesson applied in examples such as knifes, track tyres etc.

Lesson 3

Forces-Falling objects

This was the first argumentation lesson that James taught and was based on resources from the IDEAS pack (Osborne et al., 2004b). The opening activity of the lesson was a presentation of two pictures on the board (Isaac Newton and a space shuttle) and a discussion of how the two pictures could be related. Then, James asked students to look at a sheet with information regarding forces that he put on the tables before students came in the room. This included prior knowledge of forces that the students had covered in previous lessons. Students were asked to read it and think about it individually until James took the register.

<u>Information on forces</u>

To help understand the affects forces have on objects.

Get to grips with this bit first:

- You can add forces together if they are acting [pointing] in the same direction.
- If the forces are in opposite directions you subtract the smaller one from the bigger one.
- The net resultant force is the overall force acting on an object.

Now this bit:

- If the net resultant force is zero then an object will stay still OR
- If is already moving it will keep moving at a steady speed.
- If the resultant force is not zero then the object will speed up [or slow down] in the direction of the net resultant force.

The next activity focused on a picture of a car projected on the board, with the forces acting on it. James described through a series of questions and answers which are the forces acting on that car when it was standing still, when it started moving, when it started slowing down and finally, when stopping. The notions of 'gravity', 'weight', 'up thrust', 'reaction', 'thrust' and 'net force' were mentioned. Then, students were given instructions of how to work using a second worksheet (from the IDEAS pack, Osborne et al., 2004b) with a flow chart of possible statements to choose from in order to describe the forces acting on an object that was left to drop from a height of 1000 meters. Students were asked to work in pairs for this activity which lasted approximately 10 minutes and then, they were asked to share and compare ideas with another pair. This lesson offered opportunities for students to engage in the epistemic practices of justification and evaluation, as they would have to choose one of the statements provided in each stage of the fall, providing reasons for the selection. The fact that students had to choose from 2-3 statements provided further opportunities for engagement with evaluative processes as they had to make a judgement on which statement was the best. The design of the resources and the discussion that took place before the students worked in their groups, provided opportunities for the use of epistemic operations such as Explanation and Definition of concepts such as gravity, weight, forces. During this lesson, there was also scope for teacher and students to use the epistemic operations of Justification, Argument, Evaluation and Compare & Contrast.

As the lesson progressed, it was evident to James that the students found this activity challenging. Thus, after students had the chance to share ideas with another pair, he stopped then and gave more instructions of how the students should be working. The last 10 minutes of the lesson included a whole class discussion of the evidence statements provided and the choices that students made. In fact, the activity was not finished by the end of the lesson and the teacher-student discussion only reached to Statement 4. In an email after the lesson observation James said that he 'really enjoyed this lesson' although during and after the lesson he mentioned the level of challenge that students had faced was higher than what they were usually presented with.

1 There is a force of gravity on the box.

↓

2 This acts downwards.

↓

3a It is roughly the same size throughout the fall.

3b It gets a lot bigger as the box gets closer to the Earth.

3c It is biggest when the box is high up and gets a lot smaller as it falls.

↓

4a This force makes the box begin to accelerate downwards.

4b This force makes the box begin to move downwards at a steady speed.

↓

5 Once the box begins to move, there is also an air resistance force on it.

↓

6a This acts downwards, in the direction the box is going.

6b This acts upwards, in the opposite direction to the box's motion.

↓

7a The size of the air resistance force on the box is constant throughout the fall.

7b The air resistance force gets bigger as the box gets faster.

↓

8a The air resistance force on the box is much smaller than the force of gravity, and so it can be ignored.

8b The air resistance force on the box becomes quite large, and has to be taken into account.

↓

9a So the total force on the box is equal to the force of gravity, and is constant.

9b The total force on the box is the sum of the gravity force and air resistance, and this gets gradually less as it falls, because the air resistance increases.

↓

10a Therefore the box has a uniform acceleration throughout its fall.

10b Therefore acceleration of the box is biggest to begin with, and gets gradually less. Once the air resistance force becomes equal to the gravity force, the acceleration is zero and the box then falls at a steady speed.

10c Therefore the box falls at a steady speed throughout its fall.

Lesson 4

Forces

Lesson 4 was another argumentation lesson that James taught using resources from the IDEAS pack (Osborne et al., 2004b). The aim of this lesson was for students to be able to model the forces involved in projectile motion and James attempted to do that through three different contexts. Initially, he asked students to draw a football and the forces acting on it before it is kicked by a footballer and at the point when it is kicked. Students were also asked to think about how they would explain the movement of the ball with the forces they had drawn on it. This was a way to elicit prior knowledge as students had dealt with the concepts of gravity, weight, air resistance and speed in previous lessons. James then did a demonstration where he pushed a trolley and asked students to observe the motion of the object as it was pushed and then its motion until it stopped. He then asked students to talk to their pairs about the forces acting on the trolley as it moved and why the trolley stopped moving. Finally, students were asked to work in pairs in order to fill in the gaps of the IDEAS worksheet, during which they first had to discuss with their partner whether each statement was true, false or they did not know, and also, provide a reason for their answer. After students talked in pairs for approximately 10 minutes, each pair had to share, discuss and compare answers with another pair and attempt to resolve any differences. The final group activity involved all the students working in each of the four tables in the classroom (6-8 students each) to decide which of the statements they were most and least sure about. The plenary activity included students of each group discussing which statement they were most sure about. James modelled the forces acting on the golf ball by drawing a diagram on the board and talking about it. However, there was not enough time provided for the plenary activity and only one of the six statements on the worksheet was answered and justified in whole class.

The structure of the lesson and design of the resources used provided particular affordances for the engagement in evaluative practices of science. Students had to choose whether they agreed or not with each statement and in that process provide reasons that would support their answers. Additionally, they had to negotiate with other pairs about their thinking and evaluate each other's responses. Thus, the epistemic operations expected to be used during Lesson 4 were Argument, Justification, Evaluation, Compare & Contrast and Counter-Argument. Moreover, Modelling was another epistemic operation as students had to draw force diagrams. As shown through the analysis of the talk that took place during the lesson, these epistemic operations were present during this lesson, although time limitations also meant that not all statements were discussed which would also explain that 'Prompts for Counter-Argument' was found only once even though students were asked to compare answers and counter-argue.

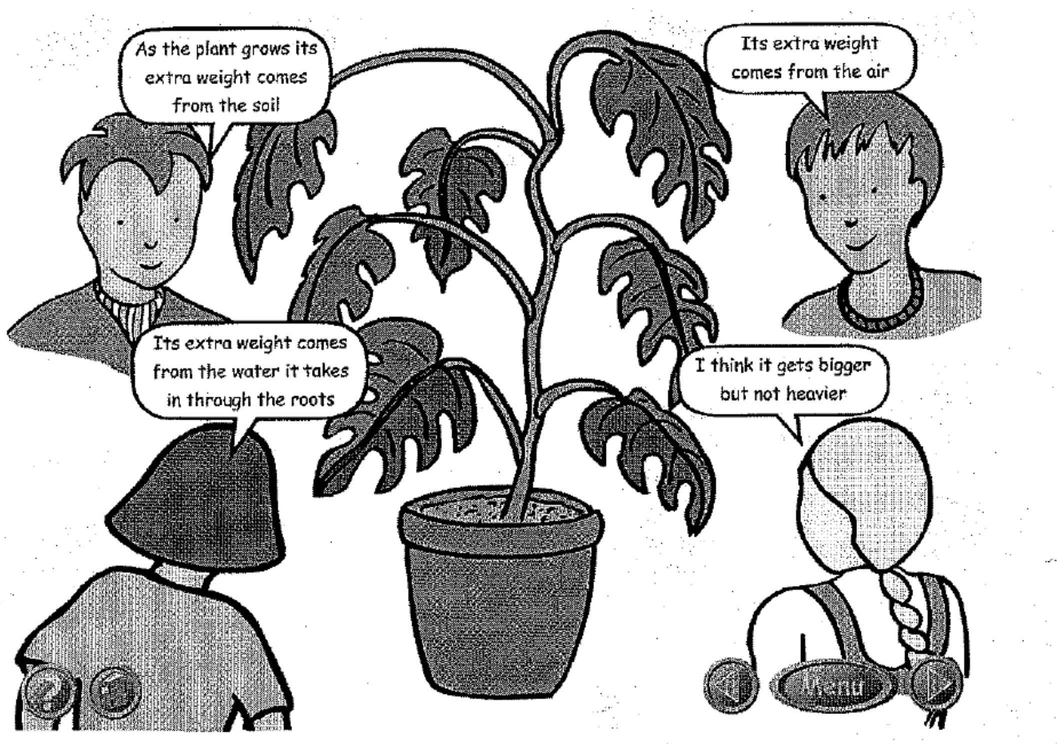
	Statement	True	False	Don't Know	Reasons
[A]	The only forces are on the ball, once it's been hit by the club, are its weight and air resistance.				
[B]	The force from the golf club acts on the ball until it stops moving.				
[C]	The force which he or she has put into the ball by striking it is being used up as it travels through the air.				
[D]	The force from his or her drive wore off at the point where the ball started to drop.				
[E]	The net force is always in the same direction as the ball is moving.				
[F]	The various forces on the ball can't be thought of as one single net force.				

Lesson 5

Photosynthesis

This lesson focused on the interpretation of data and the use of data to construct arguments in the context of photosynthesis. As a starter activity, students were given a concept cartoon (Keogh & Naylor, 1997) on photosynthesis and a number of evidence statements that they should consider and discuss with their pair.

<u>Concept Cartoon, Introductory Activity</u>



(http://www.millgatehouse.co.uk/wp-content/web-examples/ccsre/cc19.html)

Evidence Statements

Plants absorb water from the soil through their roots

Plants absorb minerals from the soil through their roots

Plants absorb carbon dioxide from the atmosphere during daylight hours

Plants release oxygen into the atmosphere during daylight hours

Plants make glucose during photosynthesis

Plants grow by making new cells

Then, James provided students with a graph, which included two lines; students had to decide which represented oxygen and which carbon dioxide and justify their answers. The next activity involved students synthesising statements from three different groups given on a different worksheet (provided below) to describe what was happening at various points on the graph. During this lesson, students were asked to look at the data provided to them in order to 'describe, explain, justify and argue' their case (see Figure 6.4). The opportunities for epistemic talk that this lesson could afford were based on epistemic operations such as 'Justification' using information provided from the graph data and prior knowledge. In fact, at the start of the lesson James told the students that 'you are gonna have to make some decisions but you're gonna have to justify those decisions' emphasising in this way the importance of providing reasons. Moreover, the lesson provided opportunities for the teacher and students to engage in the epistemic operation of 'Evaluation' as they had to make a judgement on which line is oxygen and which is carbon dioxide based on the evidence provided. Finally, opportunities for constructing arguments were also created during this lesson as James gave students a number of statements that they could use to construct a description and argue about why their statement was correct for specific points on the graph. The analysis of classroom talk showed that the epistemic discourse that took place during this lesson was among the highest from the six argumentation lessons observed with the most 'Prompts for Evaluation' and 'Prompts for Justification' found.

Instructions and statements to use

Photosynthesis living graph: Tasks

- Remind yourself of the word equation for photosynthesis
- Decide which line on the graph represents oxygen levels and which line represents carbon dioxide levels.
- Read each numbered statement below. Choose a pair that can be linked with the word **as** and decide what time of day you think is being described. Mark the pairs of numbers on the line AB on the graph. You must do this for each of the arrows marked on the line AB.
- For each description [number] that you have put on the line, find a set of matching letters that explains what is going on and write them under the number. To make a set of matching letters you must choose a beginning, middle and an end.

1. The oxygen level is rising
2. The oxygen level is falling
3. The carbon dioxide level is rising
4. The carbon dioxide level is falling

Beginnings and ends

C. The amount of oxygen produced by photosynthesis

D. The amount of oxygen being used for respiration

E. The amount of carbon dioxide produced by respiration

F. The amount of carbon dioxide being used for photosynthesis

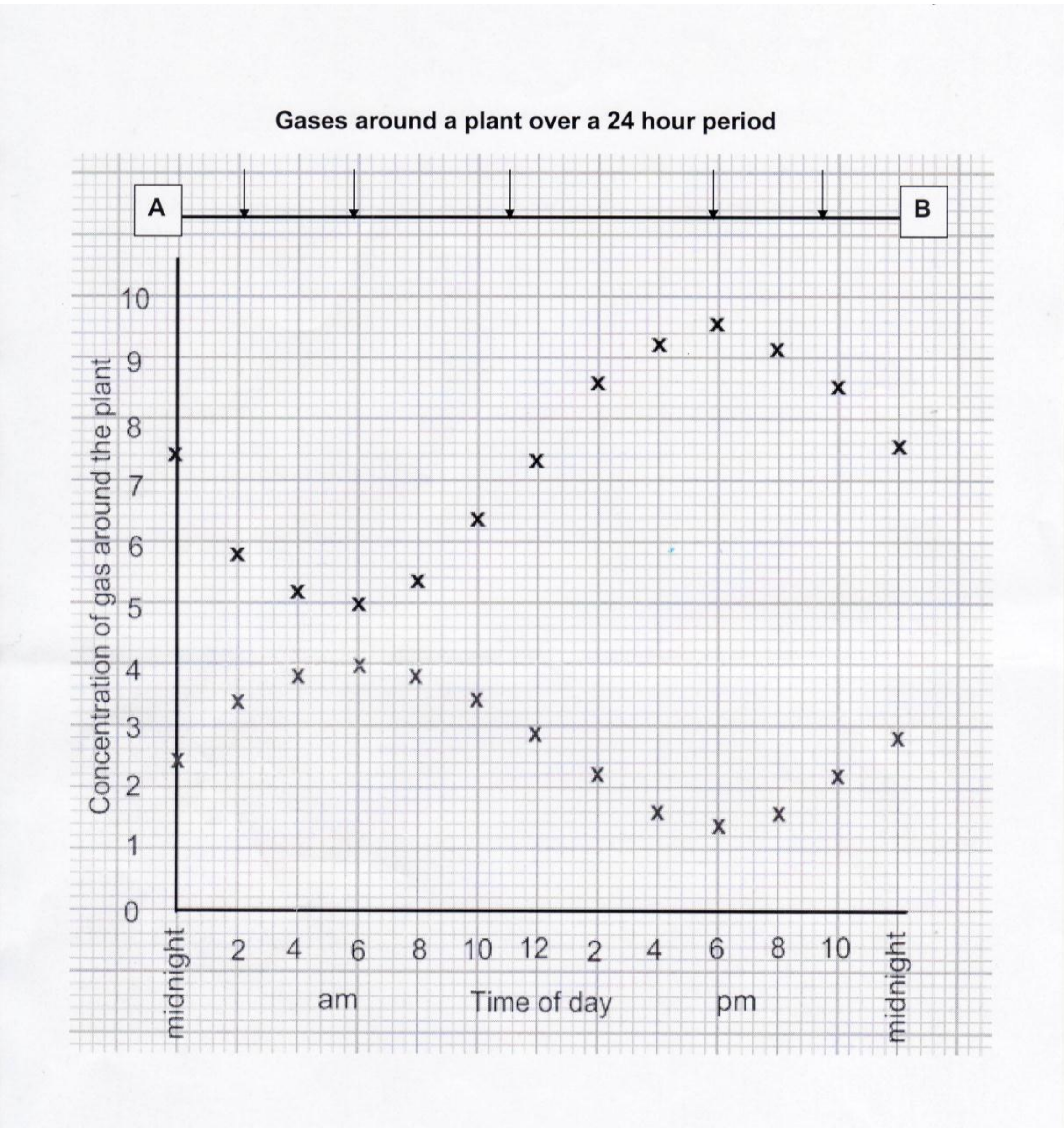
Middles

G. Equals

H. Is less than

I. Is bigger than

Graph


Gases around a plant over a 24 hour period
A
B
Concentration of gas around the plant
10
9
8
7
6
5
4
3
2
1
0
midnight
2
4
6
8
10
12
2
4
6
8
10
midnight
am
Time of day
pm

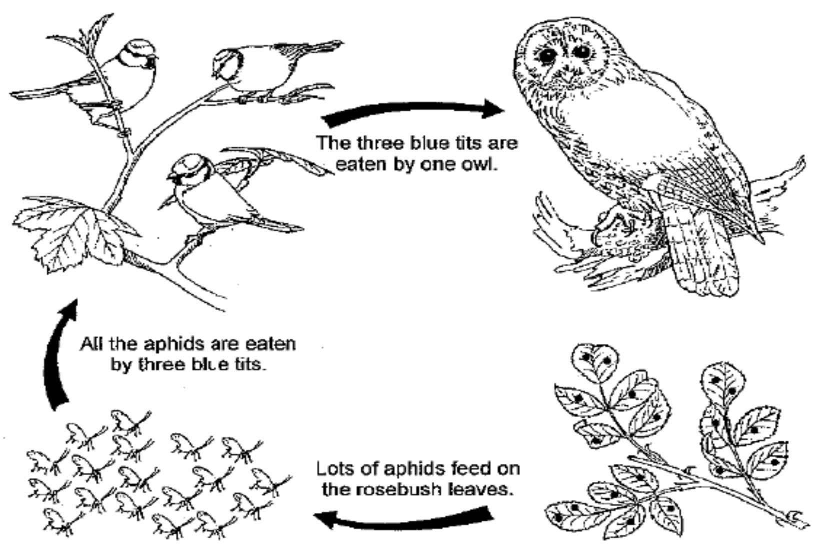
Lesson 6

Are pesticides a problem?

This lesson focused on the question ‘Are pesticides a problem?’ which was written on the board throughout the lesson. The aim of this lesson was for students to use their knowledge of pesticide use to create arguments and counter-arguments. The first activity students were engaged in involved the elicitation of prior knowledge about pesticides that students had covered with another science teacher. James provided students with the worksheet ‘Pesticides: trace the poison’ that students had to work on individually (shown below).

Pesticides: trace the poison

DDT is an insecticide. In the past, it was used to kill pests like aphids on rose bushes. Small birds like blue tits ate the aphids, and birds of prey ate the blue tits. DDT is now banned in Britain. You are going to find out why.



The 18 black dots on the leaves in this diagram represent the number of DDT particles in the rosebush leaves.

1 Divide the number of black dots by the number of aphids. Draw the black dots on the aphids to show how much DDT is passed on to each aphid.

2 Do the same with the blue tits and the owl.

ⓐ Which organism has the most DDT in its body?

ⓑ What do you think might happen to the owl?

ⓒ Why do you think that DDT has been banned in Britain?

ⓓ Suggest a different way to control the aphids on rosebush leaves.

James assigned each group a role, and gave them evidence statements, which they had to use to construct their argument. Students were also encouraged to think about what other students who were assigned different roles would say and how they could counter the other students' arguments, promoting in this way the creation of counter-argument. After students worked in pairs to form their arguments and consider possible counter-arguments, they were asked to join another pair of students that were assigned the same role, compare their arguments and create a joint argument and counter-arguments. Finally, students were given the opportunity to present in whole class their views and whether they agreed or disagreed with other groups' arguments and why.

Roles for each group

- **Red group:** you will take the role of a worried shopper who doesn't want to eat food that might contain pesticides.
- **Blue group:** you will take the role of a farmer who wants to use pesticides to increase the amount of crops she can grow.
- **Green group:** you will take the role of an organic farmer who does not want to use pesticides on his farm.

This was the first lesson that students were explicitly encouraged to create counter-arguments. Thus, there were opportunities provided to students to engage in epistemic talk through the use of epistemic operations of 'Counter-Argument', 'Evaluation', 'Compare & Contrast', discussion of evidence and 'Justification'. What is more, students were asked to work in pairs, then groups of 4-6 so there were more opportunities and time for exchange of ideas and construction of arguments within the groups, and the teacher acted as the facilitator of these discussions, continuously circulating around the groups. Finally, all groups had the opportunity to present their final work to the whole-class, which was not possible in other lessons observed previously (e.g. Lesson 4). The analysis supported the expectations of epistemic talk in this lesson with the highest number of 'Prompts for Argument' and 'Prompts for Counter-Argument' found.

Evidence Statements

9D4a **Are pesticides a problem?**

Activity Resource

Arguments

Decide which of these arguments you can use when preparing your speech for the debate.

- Pesticides are thought to be safe in very small amounts.
- Some scientists think there is no safe level for pesticides.
- Pesticides kill harmful insects.
- Pesticides kill useful insects.
- Pesticides may cause brain and nerve damage in humans.
- Without the use of pesticides, food will be more expensive.
- Pesticides are broken down very slowly and stay in our bodies for a long time.
- Food produced without using pesticides does not look as nice.
- Pesticides build up as you go up the food chain.
- Without pesticides, farmers need to employ more labourers.
- Organic farms have more birds, butterflies and other wildlife than farms that use pesticides.
- Pesticides let farmers produce more food so that few people will die of starvation.

Sheet 1 of 1

Lesson 7

Chemical reactions of carbonates

This was a practical lesson, which aimed at students identifying and modeling the chemical reactions of three different carbonates. Initially, James focused on providing students with a description of the materials and procedures they would be using. However, he did not them the purpose of all the equipment and materials they had on their tables. Instead, he asked them to consider how they could use each piece of equipment for their investigations. Thus, during this whole class interaction epistemic operations such as 'Description', 'Generalisation' and 'Provides evidence' were likely to be used. During the group investigations James' talk was mostly procedural making sure the students knew what they were doing, whether they were using the equipment correctly etc. The way that James structured this practical lesson provided opportunities for epistemic talk based on justification and evaluation as students had to make their own selections of the equipment to be used, and thus, created affordances for evaluative talk. Moreover, he asked students to justify their use of equipment and materials, for instance, 'why have you being given limewater and why have you been given a thermometer'. The final activity, required students to use tiddlywinks of different colours to represent the chemical reaction of zinc carbonate and hydrochloric acid and the products of this reaction. In particular, James wrote on the board two of the products (CO_2 and $CuCl_2$) and asked students to find which was the third product of the reaction (H_2O). This activity provided opportunities for the use of 'Modelling' by James. The analysis of classroom talk showed that evaluative talk was used through the epistemic operation of 'Evaluation', which was one of the most common discursive actions of James during this lesson. However, his prompts for students to engage in discussion and reasoning about the processes they were investigating were mostly 'Prompts for Evidence'.

Lesson 8

Which metal is the most reactive?

In this practical lesson, the main objective was students to use the materials and equipment provided on their tables to answer the question ‘which metal is the most reactive’. Information of the solutions and apparatus provided was written on the board from the start of the lesson. The instructions were:

Measure the speed of the chemical reaction between each metal and hydrochloric (HCl) acid.

Hint: **this reaction gives out heat so the thermometer may be useful and so will a stop-clock.**

You need a results table.
You need to share out the job (each pair does one metal)

Success:
NO INJURIES
COLLECT DATA ON 3 METALS
DATA IS VALID (test is fair)
PLOTTED A GRAPH OF 3 SETS OF DATA

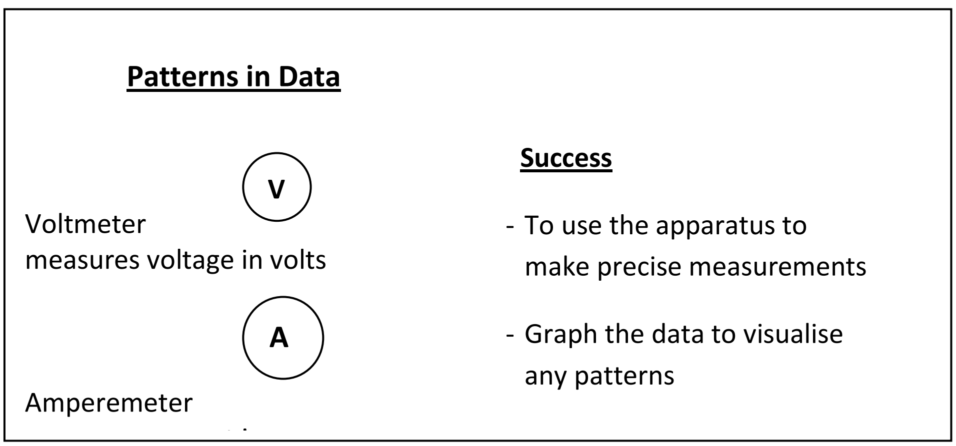
This lesson, although a practical lesson, with not many opportunities for discussion to take place, provided specific affordances for the use of evaluative talk, especially through the way in which James presented apparatus to the students. In particular, he provided the different groups with thermometers but he did not indicate how students were to use them in their investigations (although it was written as a ‘hint’ on the board throughout the lesson). In this way, he encouraged students to make a decision on the best way to use the thermometers. Throughout the investigation James circulated around the tables asking students how each of the solutions reacted and whether they figured out how to use the thermometer and stopclocks provided. Students found their own ways of using them, which James then demonstrated and discussed with the whole class. The way this lesson was organised also included some elements of argument-based instruction. For instance, the fact that the students had to provide an answer to the question provided above and had to make a judgment about the reactions of the three solutions offered opportunities for the construction of arguments, and for the use of the data collected as evidence to justify the students' views. Students needed to collect their own data, and also, they were asked to share and compare results. In this way, he promoted creativity and allowed students to take initiative of their actions and control their learning. What is more, during this lesson, James asked students to plot the data they were going to collect and compare their graphs in order to come to a conclusion about which solution was the most reactive. During this activity, he also asked students to decide how they would know that a solution would be the most reactive, prompting them to use different ways to answer this question and to determine the indicators and criteria they should use.

Overall, 'Justification', 'Prediction', 'Argument' and 'Evaluation' were the epistemic operations that this lesson offered the students and teacher opportunities to engage in. However, as the lesson progressed, the activities (and talk) focused more on the collection of data needed to answer the main question. Due to time constrains the data collected by students was not discussed at the end of the lesson, although the teacher mentioned they would do that in the next lesson where they would also talk about reliability of the data. Consequently, 'Prompts for Evidence' was found more frequently than 'Prompts for Argument' and 'Prompts for Justification', although 'why' questions had the highest frequency in the non-argumentation lessons observed (14 instances).

Lesson 9

Electricity-Patterns in Data

The main objective of this lesson was for students to learn how to ‘precisely’ handle the apparatus that they would be using in the new module they started working on (electricity). This lesson started as a practical lesson where the students would have the opportunity to get familiar with the apparatus used in a lesson about electricity, such as a voltmeter and an ammeter. However, right before the lesson started James also included another objective in order to make the lesson more engaging for the students (as he commented at the end of the lesson). Thus, students also had to use circuits to identify the relationship between current and voltage in a circuit. On the board the following information was available throughout the lesson.



The first activity required students to work in pairs to build a circuit that was given to them as a diagram (which included a voltmeter and an ampermeter). After students spent about 10 minutes working on their circuit James stopped them and through a series of ‘question and answers’, he elicited their knowledge of circuits in series and parallel and defined notions such as current and volts. Students were then given more time to construct their circuits as he rotated around the four main tables and supervised students’ work. Building the circuits took the most time of this lesson, as many of the students encountered problems with equipment that was faulty or they connected the different parts wrong and they had to start over.

'Provides evidence', 'Description' and 'Definition' were epistemic operations that this lesson offered opportunities for, as the students were starting a new module. Moreover, as the students had to build a circuit and take measurements, procedural talk about faulty equipment and problems students had with building their circuits was common.

The second part of the lesson (the last 10 minutes) required students to collect pairs of readings (voltage and current) using their circuits and plot them in order to visualise any patterns and establish the relationship between current and voltage. As in Lesson 8, where James did not provide students with direct instruction of how to use each piece of apparatus available to them, so in this lesson, James encouraged his students to consider what they needed to record their data instead of telling them what to do. Moreover, James encouraged students to get ideas from other groups if they encountered problems with their circuits instead of giving up and asking him. Consequently, a sense of sharing within this classroom was present where students were given the opportunities to act on their own, be creative and inventive in finding out how to solve their problems with their circuits and are free to consult other students. Nonetheless, most of the lesson focused on building the circuit and collecting data, with mostly talk of a procedural nature and with almost no time left for talking about the data collected and the graphs that the students should have created. In fact, many of the students did not manage to have a set of data collected by the end of the lesson, which led James giving all students a set of data that they should use to create a graph and explain the patterns they find, as a homework assignment.

Lesson 10

Forces in space

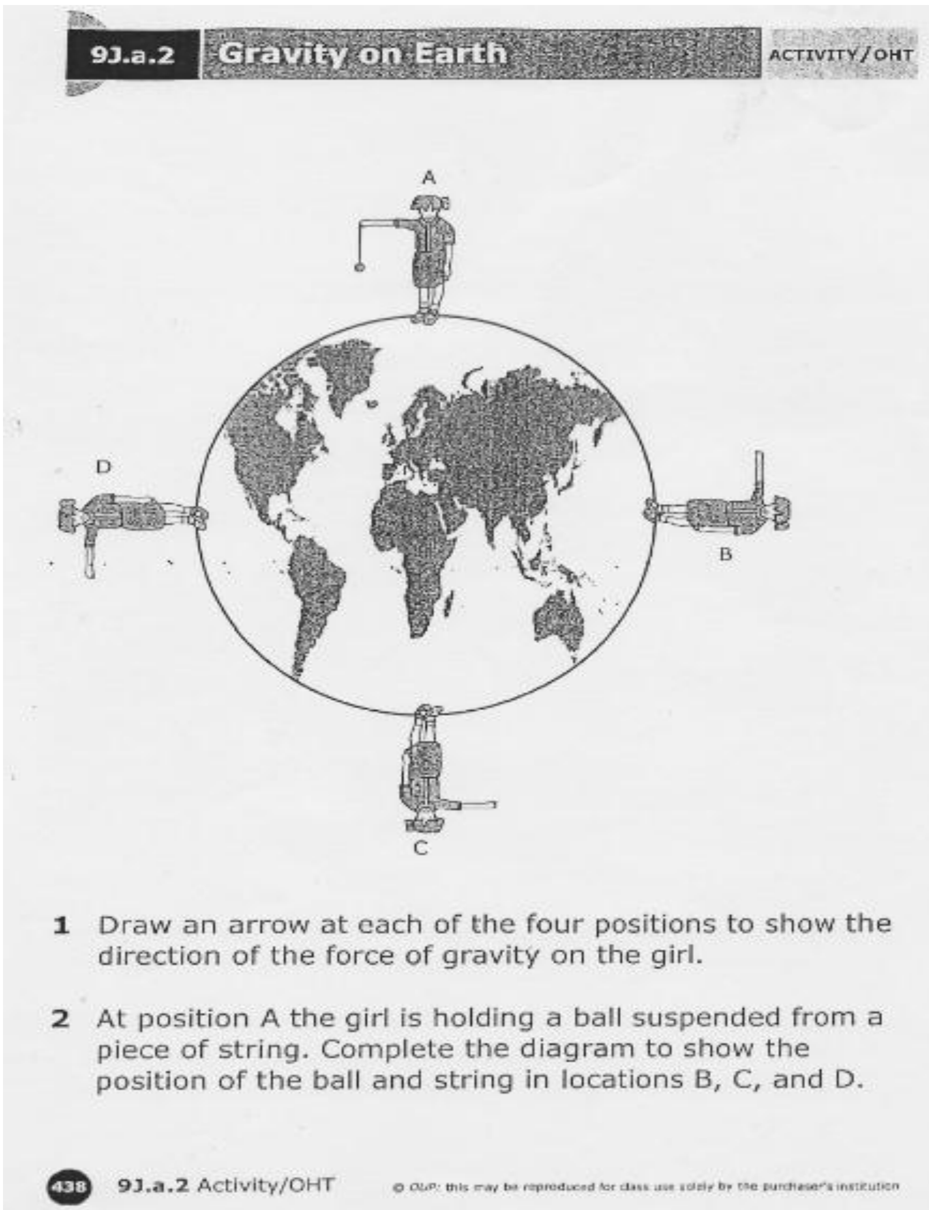
This was an argumentation lesson during which students were asked to ‘tell the story’ of an astronaut as s/he was travelling from the Earth to the Moon. To do so, students were asked to draw a diagram of the movement of the space shuttle from the Earth towards the Moon and describe the forces acting on it at different points of the journey.

The starting activity required students to consider a set of cards and match them based on the definition of each concept provided. Next, James gave students five different statements and pictures and asked them to pair the statement with the picture and put them in the right order to describe what happens to the weight of an astronaut when on the Moon, in space and on Earth. Students were also provided with pictures of three different astronauts, which included information on their weight and mass and were asked to choose which of the three matched the statements. Students worked with the statements for 6 minutes at which point, James stopped them and showed them a short film that provided students information of the Apollo 11 mission. Then, students were given the opportunity to ask questions about the film and the space shuttle. James drew a space shuttle on the board and explained to the students the purpose the various parts. Next, students were asked to work collaboratively in pairs to create their story and use the information of the cards provided to help them. In particular, James asked students to first spend about 5 minutes talking about the mass and weight of the astronaut as he travelled to the Moon and back, before they were asked to each produce a drawing with the force diagrams and short descriptions. Students could talk to their partners and share ideas and they had to ‘justify their stories’ by using the concepts of weight, gravity and mass. As with all his group-work activities, James was circulating continuously around the tables discussing and answering students’ questions.

The affordances for epistemic talk offered during this lesson was mainly on ‘Explanation’ and ‘Justification’, as James described the outcome of the students’ work as an explanation in terms of gravity mass and weight. In fact James described this lesson as an ‘argumentation lesson’ because as he said after the lesson, it offered students the chance to come up with their own ideas and attempt to justify their answers. Moreover, opportunities for the epistemic operation of ‘Prompts for Comparison’ were also present as students had to compare mass and weight at different points in the astronauts’ journey. However, the analysis of the talk during this lesson revealed that students had difficulty using the concepts of weight and gravity and often, had misconceptions about the difference between gravity and weight. These misconceptions lead to James focusing his interactions with students in prompting them for information and justification but did not focus on the construction of arguments and the use of epistemic operations such as ‘Prompts for Argument’ or ‘Argument’. The final activity involved modelling forces acting on the alien and compared that with simplified force diagrams of an object or a point, which provided opportunities for the use of ‘Modelling’.

Lesson 11

The aim of this lesson was for students to be able to use the concepts of gravity, weight and reaction and understand the relationships between them. As the students came into the classroom James gave them the worksheet ‘Gravity on Earth’ (below) and asked them to start working on it individually for 3-4 minutes.

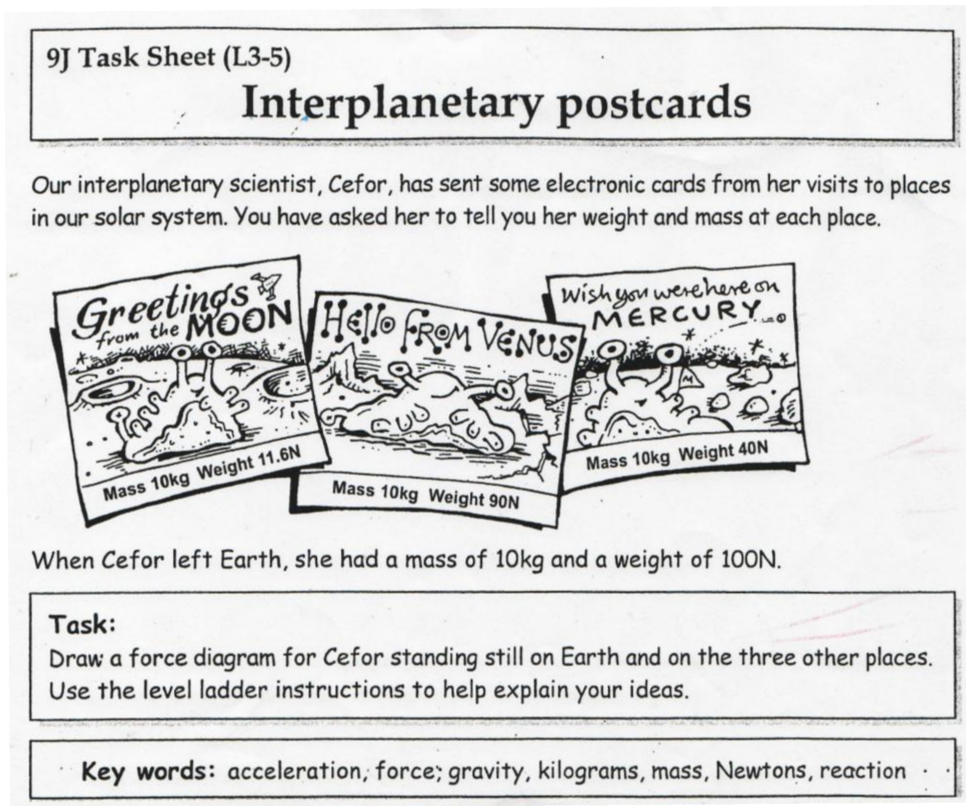

9J.a.2 Gravity on Earth ACTIVITY/OHT

1 Draw an arrow at each of the four positions to show the direction of the force of gravity on the girl.

2 At position A the girl is holding a ball suspended from a piece of string. Complete the diagram to show the position of the ball and string in locations B, C, and D.

438 9J.a.2 Activity/OHT © OUP: this may be reproduced for class use solely by the purchaser's institution

Then James talked the students through the two tasks of the worksheet and provided information on the following activity, which they should work on their own, but could talk about it with their partner. Specifically, students were given the following worksheet and were asked to draw different force diagrams to show the forces acting on the alien on Earth and other planets.



9J Task Sheet (L3-5)

Interplanetary postcards

Our interplanetary scientist, Cefor, has sent some electronic cards from her visits to places in our solar system. You have asked her to tell you her weight and mass at each place.

Greetings from the MOON — Mass 10kg Weight 11.6N

Hello FROM VENUS — Mass 10kg Weight 90N

Wish you were here on MERCURY — Mass 10kg Weight 40N

When Cefor left Earth, she had a mass of 10kg and a weight of 100N.

Task:
Draw a force diagram for Cefor standing still on Earth and on the three other places.
Use the level ladder instructions to help explain your ideas.

Key words: acceleration, force, gravity, kilograms, mass, Newtons, reaction

Students were also given a set of criteria against which to evaluate their work and to help them carry out the task. Providing this sheet to the students was a way to regulate the students' work without continuous intervention by the teacher. However, the students did not seem to be using the evaluation criteria during their work.

9J Improvement Ladder (L5-7)

Interplanetary postcards

Now your work has been assessed, choose one or two improvement targets.

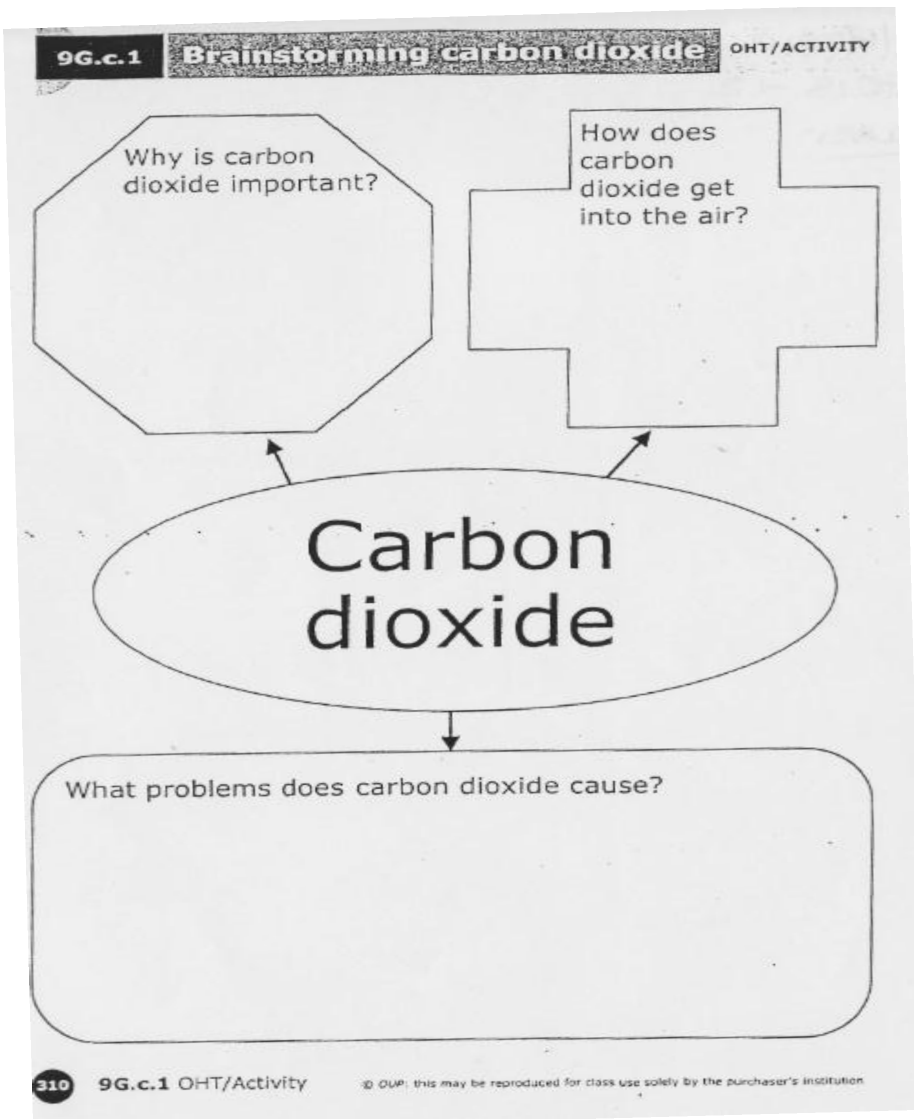
To get level	My improvement target could be to:
5	*Explain simply why Cefor's weight is different at each place by:* Drawing a diagram of Cefor in each place, using force arrows that show the direction of the force. Labelling arrows with key words. Stating whether the forces are balanced or unbalanced. Describing the difference between "mass" and "weight". Labelling the size of the forces on each diagram.
6	*Explain why Cefor's weight is different at each place by:* Drawing a diagram of Cefor in each place, using force arrows that show the direction and size of the force. Labelling arrows with key words. Explaining why forces are balanced or unbalanced. Explaining the relationship between "mass" and "weight", using the correct units. Labelling the size of the forces on each diagram.
7	*Explain in detail why Cefor's weight is different at each place by:* Drawing a diagram of Cefor in each place, using force arrows that show the direction and size of the force. Labelling arrows with key words. Explaining in detail why forces are balanced or unbalanced. Explaining in detail the relationship between "mass" and "weight", using simple equations and the correct units. Labelling the size of the forces on each diagram.

During this lesson, affordances for the engagement of teacher and students in epistemic operations such as 'Explanation', 'Provides Evidence' and 'Justification' were provided. Moreover, 'Argument' could be used, especially within Level 7, where students could provide an argument to explain why they thought forces acting on Cefor the alien were balanced or unbalanced. Finally, during this lesson the epistemic operation of 'Modelling' could be used especially during the time where students and teacher were discussing the creation of force diagrams and how to best represent forces acting on an object.

Lesson 12

Which solution is the most acidic?

This was a practical lesson during which students investigated the acidity of four different solutions. As with many other lessons observed by James, students were given a worksheet (below) as they entered the room and were asked to start working on it individually. When all students were present James discussed in whole class the answers to the questions and introduced the objectives of the lesson.



The main activity of the lesson involved students investigating the acidity of four different solutions by ranking them in order of their pH. In particular, the instructions given to the students were that they should work individually, think about how they were going to carry out their investigation, how they were going to record their evidence, and, finally how they were going to make sure that the evidence they had gathered were reliable. The four solutions given to them were rain water, sulphur dioxide, carbon dioxide, and acid rain. Other materials provided were chalk, universal indicator and marbled chips.

The structure of this lesson allowed for the use of evaluative talk through epistemic operations such as ‘Evaluation’ and ‘Compare & Contrast’ as students should compare the different solutions. Moreover, ‘Classification’ was an epistemic operation that students were engaged in as they had to rank the four solutions they were provided with. What is more, affordances of the use of ‘Justification’ were also present as students had to use the evidence collected to justify their classifications. As students were carrying out their investigation, James rotated around the tables and asked students to tell him how they would plan their investigations and why, which prompted students to engage in argument construction. In fact, this non-argumentation lesson had the most instances of ‘Prompts for Argument’ compared to the other non-argumentation lessons observed. However, procedural talk was also present to a great extent in this lesson, and as students were, at points, struggling with their practical work, James mostly used ‘Prompts for Evidence’ in his interactions with students.

Lesson 13

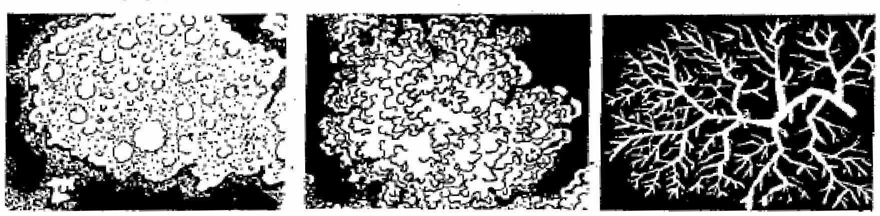
Air quality

This lesson focused on the use of evidence in order to make judgments about an issue. James initially modelled argument and counter-argument using an example from everyday life (football). During this modelling of argument, the role of evidence and justification were stressed as well as the role of counter-arguments. The next activity focused on air quality and the Earth's atmosphere. James presented students with different pictures to provide students with information about what is air quality and how it can influence individuals (e.g. asthmatic people). Then, James gave students the following worksheet which they should read and answer the questions so as to 'better understand how these kind of evidence can allow you to make a judgment about air quality'. Students worked individually although James told them that they could talk between them about the activity in order to figure out how to plot their graph. This activity lasted for about 25 minutes. The plenary activity included a whole class discussion of the answers to the questions 2, 3 and 4 of the worksheet. Although James mentioned the importance of being able to make judgements, he framed this based on the use of evidence as justification and did not consider the evaluative process that is also required in making judgements about a topic. Thus, during this lesson emphasis was placed on the epistemic operations of providing and prompting for evidence and 'Justification'. What is more, the questions included on the worksheet created affordances for the use of 'Explanation' and 'Argument' in the talk between teacher and students. A point to note is that as the questions that required the use of justification and the construction of arguments were discussed in whole class, during groupwork the students that were not able to draw their graphs quickly did not have the opportunity to use these epistemic operations and talk together in their groups as time run out before they had a chance to talk about the questions.

9G.e.2 Lichens and pollution levels — ACTIVITY

Have you noticed that many trees in built-up areas, such as town centres, don't seem to grow very well? Their growth is often stunted compared with trees growing in the countryside. This is partly due to air pollution in town centres caused by gases such as sulphur dioxide.

Lichen is an unusual plant which is very sensitive to the presence of sulphur dioxide. Because of this, a town centre is very unlikely to have any lichens growing in it at all. However, as you move away from the town centre towards less-built-up areas, you will see some hardy lichens (which are green and crusty) start to appear, followed by leafy lichens and, eventually, shrubby lichens. The more the lichen protrudes from the surface, the less pollution there is in the air.



	Number of different varieties of lichen found there:		
Distance from town centre (km)	**On walls**	**On trees**	**On grassland**
0	0	0	5
2	15	0	5
4	13	0	7
6	15	2	7
8	25	3	9
10	27	3	11
12	46	7	15
14	46	17	17
16	65	36	18

1. Draw a line graph to show how many kinds of lichen grow in each of the three places. Show the different places by using different coloured lines (be sure to add a key)
2. On which type of surface is the largest variety of lichens found?
3. Describe how the distance from the city centre affects the number of different species of lichen found there. Explain why you think this is.
4. On which surface do lichens grow quickest? Explain why you have chosen this answer.

Appendix H

James' use of epistemic operations in each of the 13 lessons observed (L3, 4, 5, 6, 10, 13 are the argumentation lessons)

Epistemic Operations ***Performed*** by the teacher	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13
Analogies&Metaphors	1	0	4	3	0	0	1	0	3	2	0	1	1
Argument	4	0	7	1	0	1	1	1	2	0	3	0	3
Compare and contrast	1	5	7	4	0	3	0	0	1	20	6	1	3
Counter-argument	0	1	9	8	0	11	1	0	0	2	3	3	2
Definition	4	5	10	6	5	7	1	1	3	7	3	3	2
Description	12	7	9	15	8	5	14	7	12	8	6	8	4
Evaluation	3	14	15	8	11	9	15	21	6	4	11	3	15
- IRE	2	12	8	3	5	4	3	11	1	0	4	1	8
Exemplification	4	10	9	8	6	2	0	1	0	6	4	2	6
Explanation	4	3	8	5	2	4	2	2	3	6	7	2	0
Generalisation	8	9	9	5	3	9	5	3	2	5	4	2	7
Justification	12	5	11	5	7	15	10	4	12	11	19	4	9
- Procedural	4	0	0	3	4	7	6	1	8	0	9	0	3
- Content-based	8	5	11	2	3	8	4	3	4	11	9	4	6
- 'Why'	5	14	16	16	8	5	7	14	1	6	4	9	9
Modelling	0	5	10	6	3	4	2	0	2	1	8	0	3
Prediction	0	0	5	0	0	0	0	0	1	0	0	1	1
Provides evidence	5	22	17	10	11	9	14	6	7	17	16	13	10
Epistemic Operations ***Prompted*** by the teacher	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**	**L11**	**L12**	**L13**
Prompts for Argument	3	2	8	11	7	17	1	6	3	0	4	10	6
Prompts for classification	0	0	0	0	0	0	0	1	0	0	0	2	0
Prompts for Comparison	3	0	1	0	5	0	2	1	1	3	8	1	2
Prompts for Counter-Argument	0	0	2	1	1	26	0	0	1	0	0	0	1
Prompts for Definition	3	0	0	0	0	0	0	0	0	0	2	1	2
Prompts for Description	10	4	1	5	8	0	1	4	2	2	7	3	8
Prompts for Evaluation	2	5	9	10	22	1	3	11	0	4	7	2	6
Prompts for Evidence	8	36	13	12	19	13	27	24	8	6	17	27	17
Prompts for Justification	4	15	15	14	19	5	7	12	1	7	11	9	4
Prompts for Modelling	0	0	0	0	0	0	8	0	0	0	3	0	0
Prompts for Prediction	2	7	18	5	4	2	5	4	5	1	0	6	2

APPENDIX I

Case study 2

A description of the affordances for epistemic talk of each lesson observed

Lesson 1, Embryo Selection

This was the first argumentation lesson observed. In previous lessons, students learnt about cystic fibrosis and IVF treatment and in this lesson Amy built on that knowledge and understanding by having students argue about different viewpoints on embryo selection. The lesson started with the presentation of a video which included leading scientists talking about IVF and embryo selection. The video begun with the question ‘Is it right to select?’ and provided both for and against views on the issue. Then, Amy asked students to get into groups of four and she provided them with different case studies, which they had to review and use as a basis for creating an argument either for or against embryo selection. Amy assigned each pair with a ‘for’ or ‘against’ position to embryo selection and asked students to write on a worksheet the key points for their argument (evidence). Students had to initially talk about the case study in pairs and construct their arguments, and then, present that argument to the other pair of their group. Students talked in their pairs for about 5 minutes before Amy asked them to share as a group of four the arguments they came up with and attempt to counter-argue (‘if they are coming up with something, can you come up with a suggestion to why that’s wrong’). The group discussion lasted approximately 6 minutes at which point Amy asked students to come to a decision based on their discussions and arguments about whether, as a group, they were for or against embryo selection.

While students were working in pairs and groups, she circulated around the different tables, prompting students for Arguments, Counter-Arguments, Justifications and Providing Evidence to answer students’ questions. The final activity of the lesson required students to decide their own personal view on the topic and position themselves on a ‘line of truth’. She asked students at different ends of the line to explain why they were for, against or in-between the two viewpoints. The way this lesson was designed and carried out, provided both the teacher and students the opportunity to engage in the construction, justification and evaluation of knowledge claims, as students were asked not only to construct arguments but also counter-arguments and evaluate each other’s views. What is more, the fact students had to find reasons to support viewpoints that were not necessarily their own, meant that they had to engage in higher-order thinking and talking about evidence and making decisions based on evidence. As a consequence, the affordances that this lesson had for engaging students and teacher in evaluative practices were high as there were activities that aimed at the discussion of differing views, the comparison of these views and the creation of counter-arguments. Indeed, the analysis of teacher talk during the lesson showed that Prompts for Argument and Counter-Argument were used, as well as Prompts for Justification (see Appendix J for details), as every time Amy prompted students to construct an argument, she also emphasised the need to provide a justification through the use of ‘why’ questions.

Lesson 2

Cloning

This lesson started with Amy projecting a picture of identical sisters on the board. She asked students to identify differences between them, discussed with students what identical twins are and explained how two individuals can be produced from only one fertilised egg. She then introduced the students to the aim of the lesson which was to provide answers to the questions (a) what are clones? and, (b) how can clones be produced? Using a question-and-answer whole class interaction sequence, Amy explained terms such as sexual and asexual reproduction, artificial cloning, unspecialised cells and used examples such as a strawberry and a spider plant, and also Dolly the ship to talk about cloning. She then gave them a worksheet with a number of questions on, such as 'what is an unspecialised cell?' and asked them to use their textbooks to get information that would help them answer the questions on the worksheet and eventually provide answers to questions (a) and (b) projected on the board. Students worked individually for about 25 minutes on this activity, although they were allowed to talk to the person sitting next to them. Whilst students were writing their answers, Amy circulated around the groups, answered students' questions and provided students with information and explanations regarding the concepts mentioned above. Then, Amy in whole class, asked students to judge their understanding of clones at that point of the lesson by assessing themselves using the 'traffic lights' method. For the last 10 minutes of the lesson, students and teacher discussed the results of a practical they had done in their previous lesson, regarding cauliflowers and cloning.

The specific affordances for epistemic discourse by the teacher that this lesson allowed were mainly 'Providing Evidence', 'Explanation', 'Description' and 'Definition', as the teacher either introduced new concepts or talked about concepts that were covered in previous lessons. Due to the nature of the activities, students did not have many opportunities to engage in discussions between them and thus, affordances for students' engagement in epistemic discourse were minimal. There were cases of teacher-student interaction while the teacher was circulating around the tables where students asked questions, but these discussions were mainly teacher-led so the use of higher-order epistemic operations would not be expected to be found in students' talk during this lesson. As expected, 'Prompts for Evidence' was the most common prompt used by Amy in this lesson, although Prompts for Justification was also found.

Lesson 3

Plate tectonics

The aim of this lesson was to summarise the information students covered on continental drift, volcanoes, and the structure of the Earth. The lesson started with a quiz of 8 questions that was used to establish the students' prior knowledge on the structure of the Earth and fossils, as Amy stated to the students. Amy asked each question and students had to provide an answer, usually consisting of one or two words on an answer-sheet (e.g. what name do we give to the centre of the Earth?). Students were then asked to swap answer-sheets with their partners in order to assess each other's work as she went through the answers in whole-class. The next activity involved Amy projecting a simulation of sea floor spreading and the consequences of that. She explained what constructive and destructive plate margins are, and how earthquakes are created. Then, Amy gave students a number of statements, which they had to put in the right order in order to summarise and sequence the events that take place at plate boundaries. She also provided students with four pictures that they had to match to the statements. Each student was asked to work individually to produce a piece of work. This activity lasted for the remainder of the lesson (about 30 minutes). As the students worked on their assignment, Amy circulated around the room, answered students' questions and monitored students' work.

As in the previous lesson observed, because the students had to work individually there were not any opportunities for discussion and epistemic discourse to be developed by the students. The main epistemic operations expected to be found in this lesson by the teacher were 'Prompting and Providing Information', 'Description' and 'Prompting for Classifications' as the students had to classify events in either constructive plate margins or destructive plate margins. Also, the quiz activity provided affordances for the use of 'Evaluation' as the answers were discussed in whole class. The analysis of classroom talk also revealed that during this lesson, Amy used the epistemic operation of 'Justification' considerably more than other epistemic operations in her talk, although she did not prompt students to provide any justifications.

Evidence statements

The Earth's outer layer is made up of about 12 giant slabs of rock, and many smaller ones. These are called **tectonic plates**.

The ocean floor continually grows wider at an **oceanic ridge** by **seafloor spreading**.

Movement of the plates can cause **earthquakes** at plate boundaries.

This is called a **constructive plate margin**.

This is called a **destructive plate margin**.

At a destructive plate margin the rigid plates move slowly and push against each other.

Convection currents in the Earth's mantle carry the plates along.

Volcanoes are also common at plate boundaries, where the Earth's crust is being stretched, compressed or uplifted.

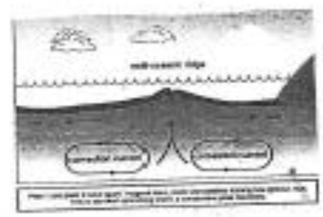
Ocean floor is destroyed where the plate dips down beneath an oceanic trench.

Example of a student's work

Plate tectonics

2nd December 2004

The Earth's outer layer is made up of about 12 giant slabs of rock, and many smaller ones. These are called **tectonic plates**.



Convection currents in the Earth's mantle carry the plates along.

The ocean floor continually grows wider at an **oceanic ridge** by **seafloor spreading**.

This is called **a constructive plate margin.**

Ocean floor is destroyed where the plate dips down beneath an oceanic trench.

STRIKE-SLIP FAULT

This is called a **destructive plate margin.**

At a destructive plate margin the rigid plates move slowly and push against each other.

Movement of the plates can cause **earthquakes** at plate boundaries.

Volcanoes are also common at plate boundaries, where the Earth's crust is being stretched, compressed or uplifted.

Lesson 4

Geo-hazards in the news

The objective of this lesson was for students to investigate and learn about different geo-hazards. Students were asked to work in groups and using different sources of information (textbook, Internet, video presentation) they had to create a presentation of a geo-hazard assigned to them by Amy. This activity had started in the previous lesson and students had to finish their presentation by the end of this lesson and present it to the whole class in the next lesson. At first, students were shown a 5-minute video focusing on two geo-hazards: the first was a volcano eruption in Colombia and the second, an earthquake in San Francisco. Amy encouraged students to listen to the information provided in the video and think about possible ways in which each country's government could act to ensure they are better prepared for such dangers. Presentation criteria were written on the board throughout the lesson and where: (a) facts about your country/region; (b) what problems does your country face, and (c) how will you spend the money? (methods to reduce damage). After the video was shown, students got in their groups and started working on their presentations for the remaining 35 minutes of the lesson. While students were working in groups, Amy went around and asked them questions to assess their understanding of the task and their knowledge of the geo-hazards they are working on and finally, to monitor students' progress.

This lesson offered students opportunities for discussion and negotiation of the different elements that should go in the presentation. The teacher's talk was mainly focused on providing and prompting for information, although affordances for the use of epistemic operations such as 'Argument', 'Prompts for Argument', 'Evaluation' and 'Compare & Contrast' were also present, as students could be encouraged to create an argument of which was the best way for governments to invest their money in order to be better prepared for geo-hazards. However, as Amy circulated around the different groups, she often had to answer questions of a procedural nature, and provide students with guidelines of what their presentation should include and why, in order to meet the criteria set on the board. Thus, Amy also used the epistemic operation of Justification in this lesson, although this focused on procedural matters rather than epistemic. Overall, although this lesson offered opportunities for engagement in epistemic discourse, these were not taken by the teacher and students.

Lesson 5

What killed the dinosaurs?

This was an argumentation lesson and the main objective was for students to use the information they had explored in previous lessons to answer the question '*What killed the dinosaurs?*' Initially, students were shown a 5-minute video-clip, which provided information and an explanation of the meteorite collision theory. Amy prompted students to consider what may have caused the extinction of the dinosaurs as they watched the video-clip. After the video ended she discussed in whole class different consequences of the collision theory for the earth (tsunamis, lightning and fires, earthquakes etc.) which might have had an influence on dinosaurs becoming extinct. Then, she used the textbook to introduce students to conflicting evidence to the collision theory and asked them to work in groups of four to classify a set of evidence statements. The evidence should be put in four categories: for and against the meteorite collision theory, and for and against the super-volcano eruption theory. She allowed students about 15 minutes to read, understand and categorise the evidence, whilst she went around the groups prompting students for justifications and arguments.

<u>Evidence cards</u>

There have been 11 major extinctions in the last 300 million years. Scientists have shown 7 of these coincided (happened at the same time) with huge volcanic eruptions

There are basalt rocks in Scotland that were formed 58million years ago. There were no mass extinctions then.

A mysterious clay layer containing iridium was found at various points around the world. This layer is 65 million years old.

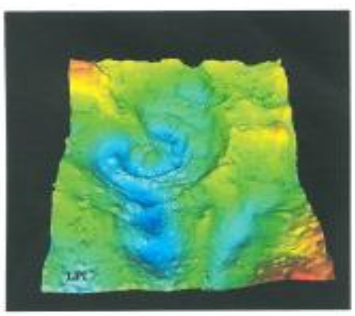
Tertiary rocks

Iridium clay layer

Cretaceous rock

Iridium is commonly found in asteroids and meteorites.

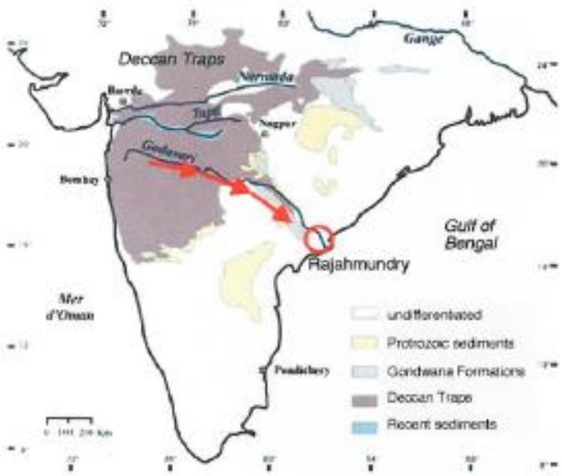
A large asteroid crater was found off the gulf of Mexico in 1990 – this is called the Chicxulub impact crater. The crater has been dated to around 65 million years ago.



Site of impact crater

Many dinosaurs and animals began to die out before 65 million year old asteroid struck.

Other large impact craters do not coincide with other mass extinctions



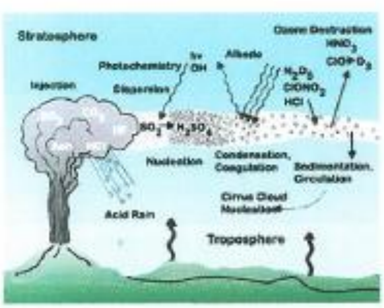
Black Igneous Basalt rock

The Deccan Traps formed between 60 and 68 million years ago,[2] at the end of the Cretaceous period. They consist of layers of black igneous rock. A third of the whole of India's surface is covered in this rock.

The basalt rock in the Deccan Traps came from huge lava flows following massive volcanic eruptions. The bulk of the volcanic eruptions occurred in the west of India. The eruptions were most intense 65 million years ago but they started before then.

Poisonous Gases

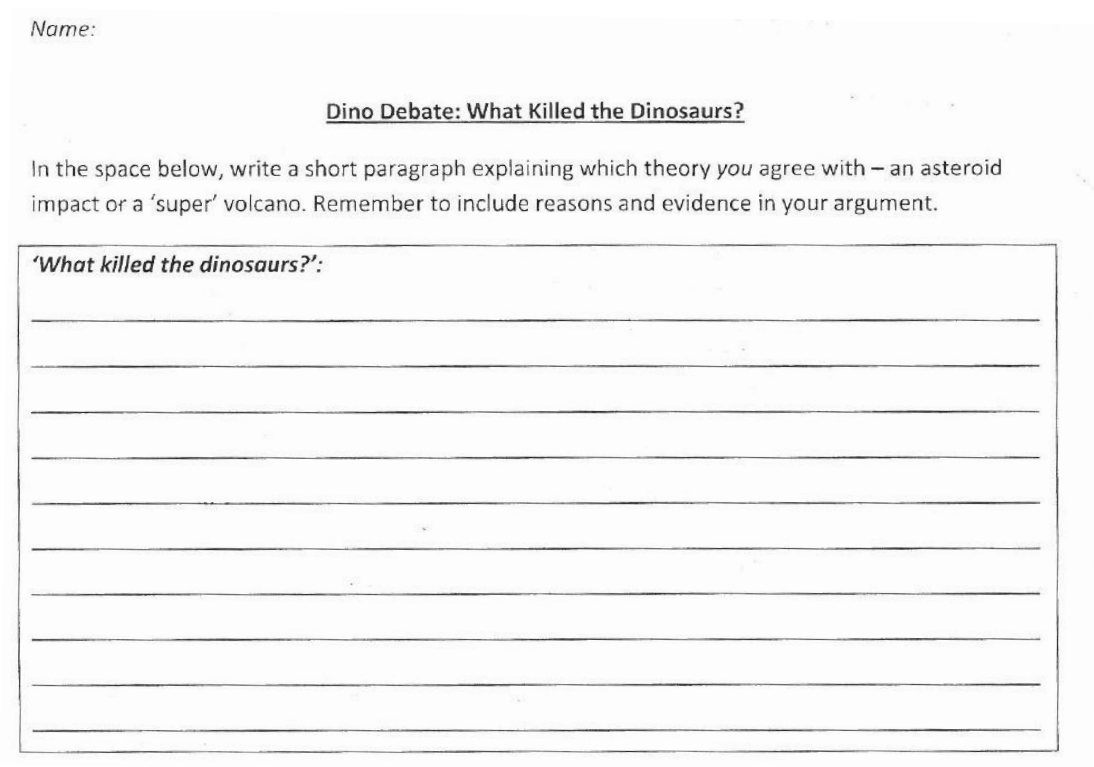
Volcanic eruptions release a cocktail of acidic gases like Sulphur dioxide (SO_2) and other poisonous gases. Huge amounts of these gases would have been released in these massive eruptions.



It may have rained down acid for years and years.

The next activity required students to decide for themselves which theory they believed was the best and then write their argument on a worksheet provided. Before the students started arguing about which theory was the best, she modelled argument by explicitly asking students to write what they thought and then support it by reasons and evidence. She also mentioned the importance of being persuasive in order to convince others. She gave students 5 minutes to write their argument on the worksheet during which she talked to a few groups about their opinions, prompted them for arguments, evidence and counter-arguments.

Written argument worksheet


Name:

Dino Debate: What Killed the Dinosaurs?

In the space below, write a short paragraph explaining which theory *you* agree with – an asteroid impact or a 'super' volcano. Remember to include reasons and evidence in your argument.

'What killed the dinosaurs?':

Then, she asked students to create a 'line of truth' with students believing to either of the two theories standing on opposite sides of the room and students believing in both standing in the middle. Based on students' opinions, she paired students from the opposite sides and asked them to take turns in presenting their arguments and attempting to convince each other. In the plenary activity Amy compared what the students were doing by using their imagination to piece the evidence together and come up with their own theory to what scientists do when they have to use imagination and creativity in order to piece together the evidence they have gathered. She also discussed how scientists do not know yet which theory is the right one as 'science doesn't always hold all the answers'. This lesson created particular affordances for the engagement in epistemic discourse by teacher and students. In particular, 'Argument', 'Counter-Argument', 'Evaluation', 'Justification' and 'Compare & Contrast' could all be used as the students had to construct arguments and counter-arguments, evaluate evidence and provide reasons in their arguments (instruction on argument worksheet), and compare the two theories. The analysis of classroom talk showed that the expectations for epistemic talk were similar to the epistemic operations identified in the teacher's talk.

Lesson 6

Handling data and plotting graphs

The objective of this lesson was students to use and understand concepts such as error bars and outliers, to be able to calculate means and averages and, to be able to interpret data. The lesson started with Amy presenting students with a set of data that she used to introduce students to the concepts mentioned above. This introductory activity lasted for about 10 minutes at which point, Amy gave students a worksheet and asked them to work individually on it presenting it as 'a bit of an assessment on how well you deal with data' and which students had to work on under 'mini-test conditions'.

<u>Worksheet</u>

Children in Iceland can't blow bubbles!

Children like blowing bubbles. You can buy bubble blowing liquid in shops – but would it be worth buying it if you lived in Iceland? Not according to our results!

<u>What we did</u>

- We kept bubble blowing liquid at 5 different temperatures
- For each temperature, a little bit of liquid was placed on a loop
- One researcher blew bubbles
- The second researcher counted how many there were

<u>These are our results</u>

Temperature ° C	Number of bubbles blown					
	Repeats					
	1	2	3	4	mean	range
0	3	3	3	3		
5	3	4	5	3		
10	1	5	6	6		
20	8	9	7	7		
50	1	12	15	14		

1. Circle any results that you think are **outliers** – should these outliers be included in the data? Give a reason for your answer

____

____

2. Work out the **average (or mean)** number of bubbles at each temperature and write it in the table (use whole numbers)

3. Work out the **range of results** at each temperature and write it in the table

4. When you look at the repeats for each temperature, they are not identical

   Suggest a reason for this

   a. to do with the equipment used

   ____

   b. to do with the method used or the skill of the researchers

   ____

5. Why is it better to repeat each temperature four times rather than just do it once?

____

____

6. The results for 0°C are ___________ reliable than those for 50°C.

   I know this because ____

   ____

7. Draw a graph of the mean results

8. Add error bars to your graph

9. What conclusion can you draw from the graph

____

____

10. One of the researchers says there is a **real difference** between the number of bubbles you could blow outside on a cold day in Iceland (5°C) and the number you could blow on a sunny day in England (20°C)

    a. What does she mean by a **real difference**?

    ____

    ____

    b. Do you agree with her? Is there a **real difference**? Use your graph to explain how you know

    ____

    ____

    ____

Before the students started working she explained the context of the data given to students and did a short demonstration of bubble blowing. She also discussed with students a set of criteria for the graphs they should produce for Question 7. Students mentioned including a title; setting units and labelling the axes of the graph; using even scales; and finally, plotting the data correctly. Students worked on their own for the remainder of the lesson (about 35 minutes), although discussions amongst students were taking place throughout the lesson. At the end of the worksheet there was a self-assessment table which students should complete at the end of the lesson.

Self-assessment table

Do you know how to handle data?

When you get your homework back, **go through the table ticking off** what you think you can do and **underlining,circling or drawing next to one part of your work** that acts as evidence for the particular skill you have ticked. Your teacher will fill out the final column.

Skill	Question	I think I can do this (tick box and show evidence of this in your work)		Does your teacher agree with your Judgement?
I can identify outliers in a set of data	1		Put a triangle next to your answer △	
I can decide whether or not to discard outliers and give reasons for doing so	1		Put a circle next to your answer ○	
I can calculate the mean of a set of repeated results	2		Draw a moon next to the place ☽	
I can suggest the range within which the true value probably lies	3		Put a star next to your explanation ☆	
I can suggest reasons why the repeats of a measurement are not always the same	4		Put a square □ next to your answer	
I can explain why repeating measurements leads to a better idea of the true value	5		Put a heart next to the answer ♡	
I can understand what is meant by **reliable** data – I can see if a set of data looks reliable	6		Underline the answer	
I can explain how I know if there is a **real difference** between two sets of measurements	10		**Highlight** the answer in colour	

In the space below, list any of the ideas above that you would like your teacher to help you with

As in previous lessons observed, Amy circulated the room and talked with students answering questions, helping them understand the task and monitoring progress and behaviour.

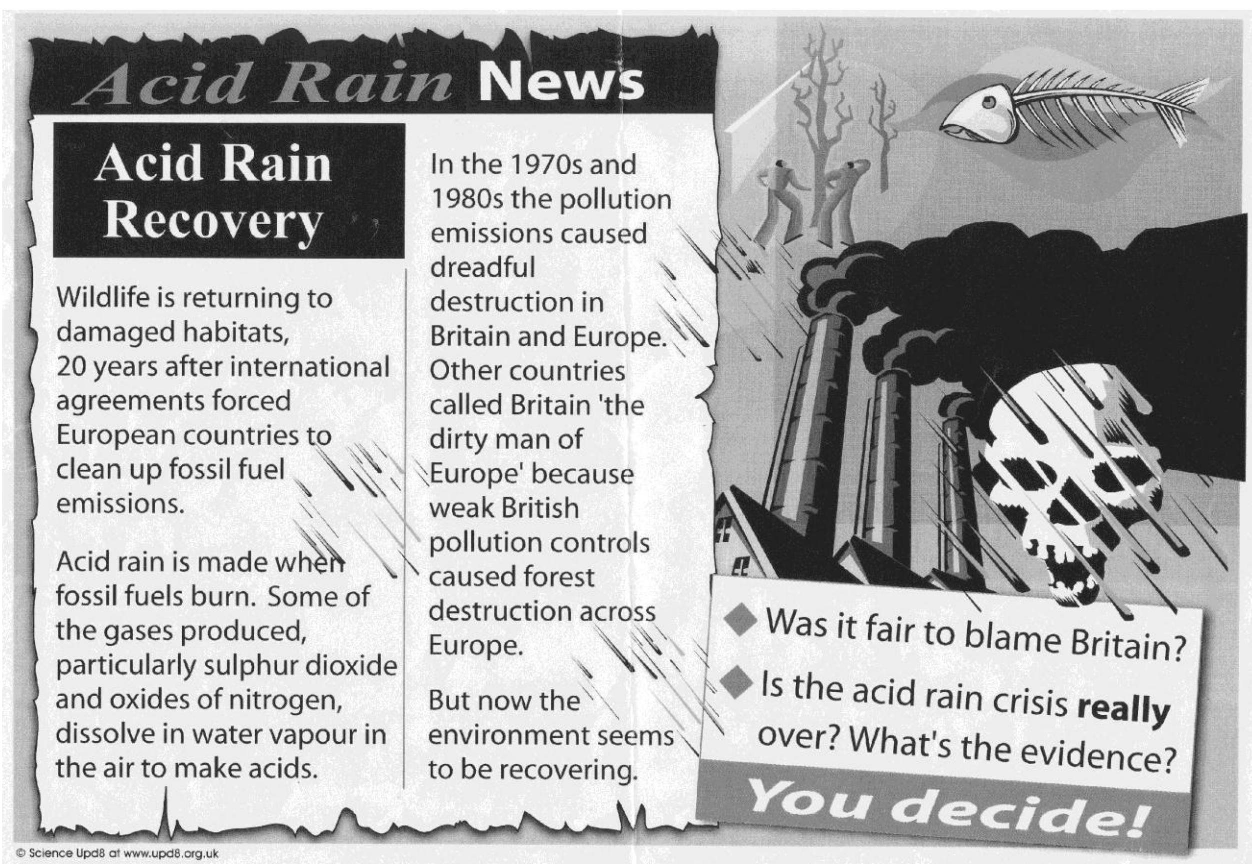
This lesson provided opportunities for the use of epistemic operations such as ‘Description’ and ‘Providing Evidence/Information’. There were also opportunities for engagement in justificatory talk as many of the questions required students to provide reasons to support their answers (Q1 and Q4) or asked ‘why’ (Q5). Based on Questions 4, 9 and 10 ‘Prompts for Evaluation’ and ‘Prompts for Argument’ could also be used by Amy as the students were working on these activities. The analysis showed that as the lesson progressed, Amy prompted students for ‘Justification’, ‘Evaluation’ and ‘Argument’ a number of times, which showed that the use of the worksheet helped in structuring the epistemic discourse that took place between teacher and students. However, as the students were asked to work independently on these questions, there were not any opportunities provided for students to engage in epistemic discourse between them, unless Amy was at their table talking with them. Moreover, as the last page of the worksheet was a self-assessment exercise which could provide the basis for the use of evaluative talk. Yet, this last sheet was not discussed with students either in whole-class or during individual work.

Lesson 7

Acid Rain

This was an argumentation lesson during which students had to investigate and answer the questions (a) Was it fair to call Britain, the dirty man of Europe? and (b) Is the acid rain crisis really over? Amy introduced students to the topic and gave them instructions on what they were going to do, which was to work in pairs to look at evidence in order to make a decision about the two questions. She then projected some information from a newspaper article on the board and asked a few students to read it aloud. Amy discussed with them about the problem of acid rain and elicited the students' prior knowledge on pollutants. She also encouraged students to state their opinions in relation to the information provided on the sheet.

<u>Information sheet</u>



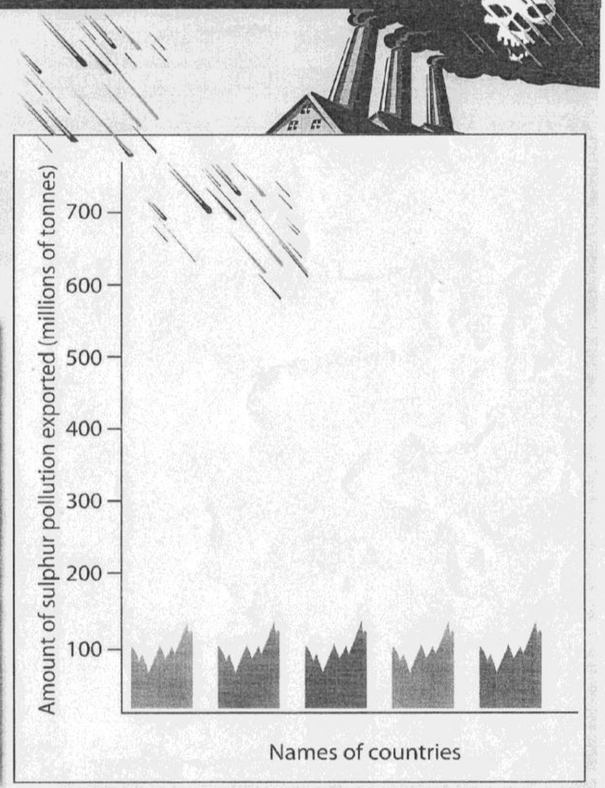
For the next activity, Amy provided students with a set of data and asked them to (a) calculate the pollution created by each European country and (b) to create a bar chart in order to show the 5 countries with the most pollution export. Students worked in pairs for this activity for approximately 10 minutes.

Worksheet

Acid Rain : who was to blame?

- Fill in the last column.
- Sort the countries into 3 groups:
  - Countries that make much more sulphur pollution than they receive
  - Countries that make much less sulphur pollution than they receive
  - Countries that make about the same amount of sulphur pollution as they receive.
- Finish the bar chart to show the 5 worst pollution exporters.

Country	Sulphur put into the atmosphere (millions of tonnes) in 1992	Sulphur that fell on the country in acid rain (millions of tonnes) in 1992	Difference between production and pollution (millions of tonnes)
Belgium	44	42	
Denmark	14	30	
France	228	202	
Germany	912	221	
Great Britain	512	41	
Holland	16	60	
Hungary	133	46	
Norway	6	109	
Poland	500	340	
Spain	313	53	
Sweden	23	98	
Switzerland	8	50	



Then, Amy asked students to join another pair and as a group of four discuss the evidence they had in front of them as to provide answers to the two questions set at the beginning of the lesson. Students could also use another set of evidence statements that included information on pollutants, acid rain and pollution levels. Amy explicitly asked students to use evidence and reasons to support their answers, which they had to write on a worksheet and gave students about 15 minutes to review the evidence they had and construct their arguments.

Written argument worksheet

"Was it Fair to Call Britain the 'Dirty Man of Europe'?"	"Is the Acid Rain Crisis Really Over?"
Group Conclusion:	**Group Conclusion:**
Evidence and Reasons:	**Evidence and Reasons:**

During this lesson, there were affordances for the engagement of students and teacher in creating arguments, prompting and providing justifications based on the evidence available. In addition, there were opportunities for the use of evaluative talk since the students had to make comparisons between the data provided for each country. Evaluation as an epistemic process was promoted in this lesson through the way that the two questions were phrased, which asked students to decide whether they agreed with the statement 'Britain is the dirty man of Europe' and justify their selection. As Amy rotated around the groups she also prompted students to think about counter-arguments and the evidence they would use to rebut other group's arguments. At the end of this activity, she had a whole-class discussion about the difference between evidence and 'reasons'. She explained evidence as data and reasons as the warrants for that data. (e.g., evidence: butterflies have returned, reason: less pollution). The final activity required students to assign themselves with a letter (A, B, C, D) and then asked students with the letter B to go to a different group, present their group's argument and compare their views. Her plenary discussion at the end of the lesson focused on students' ability to work well together and also, the importance of looking for evidence that can support a view. In particular she emphasised the need to use evidence in order to 'come up with informed decisions' and being able 'to tell the difference between evidence and speculation, someone coming up with something'. Thus, the epistemic operations of 'Evaluation', 'Justification' and 'Counter-Argument' were found in this lesson's classroom talk.

Lesson 8

Improving air quality

This was one of the last lessons on unit *C1: Air Quality*. Amy wrote on the board the title of the lesson (Improving Air quality) and also put up poster presentations of students from previous years. The main objective of this lesson was for students to work in groups of 5 during which students were given an issue on air quality and were asked to produce a teaching aid focusing on one solution to their problem. The topics students had to work on included presenting legislation that improved air quality set by the government, types of fuels that can improve air quality, the use of catalyst convertors, etc. Students should be able to use their posters to inform other people of their solutions to different pollution problems. Before the students started working on their poster presentations, Amy reviewed information they had covered in previous lessons, and prompted students to think about ways of saving energy and reducing pollution levels. Being aware of carbon footprint, new technologies and financial incentives such as the use of a congestion change in central London were some examples discussed. Then, she set a number of criteria that students should use in developing their posters. These criteria would be used by all students in the next lesson to decide which poster was the best. The criteria set were (a) presentation, (b) how well the criteria are met, and (c) clarity of language. Students were given textbooks to use as information sources and had laptops they could use to get information from the Internet.

This lesson offered opportunities for teacher and students to engage in epistemic discourse as the students were working in their group by prompting students to provide arguments based on how each of the solutions they would suggest would improve air quality. However, as the students worked in their groups, the talk that took place between teacher and students was procedural in giving instructions on setting up the group tables and maintaining student focus on the task. Students were not engaging with the task during this lesson, which resulted to Amy prompting them for evidence and descriptions and not prompting them to engage in higher-order thinking and talking.

Lesson 9

Revision on Unit C1 (Air quality)

This was a revision lesson on Unit C1. The first activity was a quiz of 10 multiple-choice questions that Amy projected on the board one by one. Students had to write their answers on a piece of paper and at the end, she went through the questions and answers with the students explaining each answer and answering student queries. The questions were mainly focusing on factual information and definitions such as outliers, pollutants etc., and the activity lasted for about 20 minutes. At the end of the quiz, Amy summarised the information that was contained in the quiz and that students should know about their exam in the form of a list that she wrote on the board. For the remainder of the lesson Amy asked students to go through unit C1 in their textbooks and based on the list she put on the board, make revision notes or go through their workbooks and try to answer questions that they are not sure about. While students were working individually she circulated around the room and answered students' questions. The talk that took place during this lesson was characterised by providing students with information, explanations, examples and also prompting students for information in order to assess their level of understanding of Unit C1.

Lesson 10

Revision on Unit P1 (The Earth and the universe)

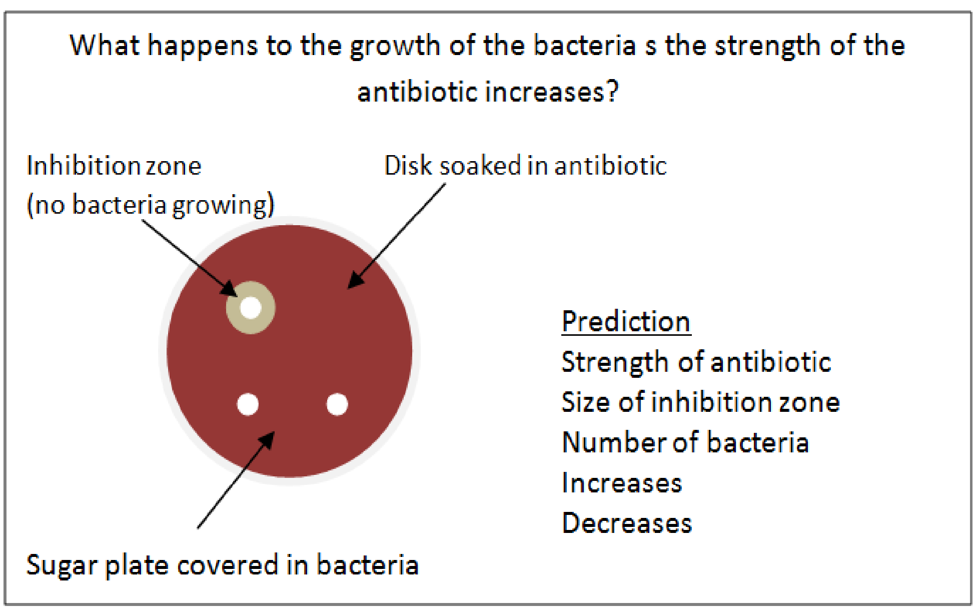
Lesson 10 was another revision lesson observed, which focused on Unit P1 (The Earth and the Universe). As in the previous lesson, Amy started the lesson with a quiz consisting of 8 questions that students had to answer. This quiz activity took place in whole-class with Amy projecting the multiple-choice questions on the board and students writing their answer on a whiteboard. For each question, students should show their answer by holding up their whiteboard for everyone to see. Each time, Amy would provide an evaluative comment on how well the students did and provide further information or explanation if necessary. The quiz activity lasted approximately 20 minutes. For the remainder of the lesson, Amy asked students to go through the P1 unit in their textbooks, make a list of the main points of the unit and for each point in their list assess their understanding. This self-evaluation exercise was to be used by Amy to plan the next revision lesson. Students were then asked to answer revision questions in their workbooks. This lesson provided opportunities for talk that focused on 'Provides Evidence', 'Prompts for Evidence' and 'Explanation'. Due to the nature of the questions in the quiz there were also opportunities for justificatory talk, especially those that asked 'how' or 'why'. Indeed, the analysis showed that Amy used 'Justification' frequently although 'Prompts for Justification' were not present in her talk.

Lesson 11

Antibiotic Investigation

This was a practical lesson where the students investigated the influence of antibiotics on bacteria growth. As the lesson begun Amy had the question 'What happens to the growth of the bacteria as the strength of the antibiotic increases?' projected on the board. She reminded them what they did in the previous lesson (setting up a petri dish with 3 disks that had different strengths of penicillin on them, and a fourth with just paper to use as a control). She gave students their petri dishes from the previous lesson and she explained what the students could see by projecting on the board a slide with a diagram of a petri dish containing bacteria and explained what an inhibition zone is. On the same slide, she also emphasised the importance of making predictions. She emphasised the importance of making predictions in scientific investigations and students were asked to make observations and predict what they think would happen using the terminology on the board.

<u>Information projected on the board</u>



She then went around the groups and looked at some of the students' work with them and helped them describe what they had on their dishes. After she gave students a few minutes to look at their dishes she held a whole-class discussion about the students' predictions. She focused on what a prediction is and why it is important. What is more Amy defined prediction as 'an educated guess' or 'something you can support with evidence'. Then, she asked students to write in their notebooks their predictions of what should have happened to bacteria in their petri dishes but as she went around the tables to monitor the students' work, she got a lot of questions from students about prediction. Thus she asked students in whole-class how they could use the words she had on the table (under Prediction) in order to state what would happen if the strength of the antibiotic used increased or decreased.

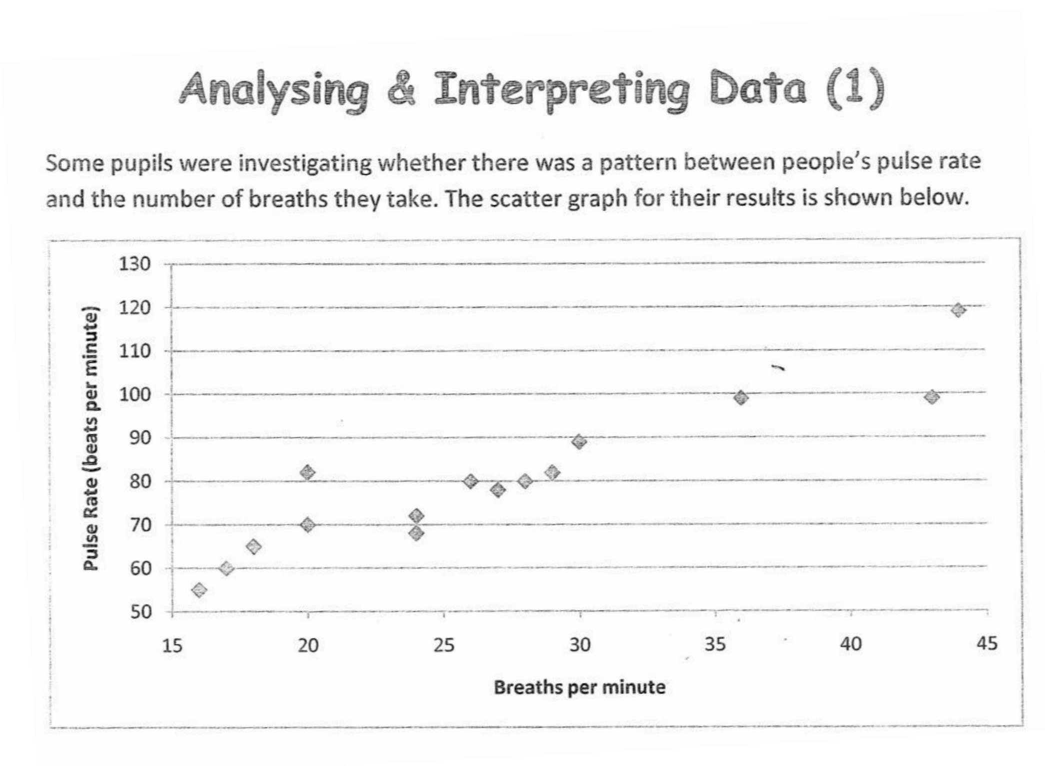
The next activity required students to use a set of data given to them representing different levels of strength of antibiotics and the inhibition zones created. Students had to calculate means, identify outliers and the range of the results. Students worked for about 10 minutes on their calculations before Amy went through the results with them in whole-class explaining how students should choose outliers and discussing how the results obtained from investigations can be reliable. Then, students were asked to draw a graph using the data. As in previous lessons observed, Amy discussed the criteria for drawing graphs with the students. She asked them to decide which variable they should put on the X and Y axes. She put a list of criteria on the board for students to see as they worked on their graphs (title, scale, labelled axes, units, correctly plotted, line of best fit). She then went around the tables overlooking the students' progress. However, there was not enough time for the students to complete their graphs which Amy asked them to do as homework. During this lesson, the concentration levels of students were low and Amy had to interrupt the lesson a number of times to ask students to calm down. The affordances for epistemic talk that this lesson provided were through the use of 'Prediction' and 'Prompts for Prediction' and 'Compare & Contrast' when students were examining their petri dishes. The analysis showed that comparisons were not made but students and teacher did engage in making predictions. Moreover, as the students were not very concentrated during this lesson, Amy mainly used 'Prompts for Evidence' with the students.

Lesson 12

Handling and analysing data

This was an argumentation lesson Amy adapted from the IDEAS pack (Osborne et al., 2004b). The objective of this lesson was to reinforce the students' ability to interpret data collected from their practical investigations. At first, Amy asked students to watch and listen carefully at a YouTube video-clip which showed female marathon runners having difficulty reaching the cross-line of the race. One student asked 'why are they doing that?' and Amy used the students' question to start a whole-discussion trying to explain the athletes' behaviour. Though this question-and-answer sequence, she explained to students how energy is used in breathing, and how breathing rate is influenced in that process. Then, she gave students a graph which showed the relationship between pulse rate and breaths per minute. She gave each student a post-it note and asked them to identify the pattern in the graph and any questions they would like to know for the given graph. Students worked individually for about 5 minutes as she went around the tables and checked their work and the questions they were writing.

<u>Graph given to students</u>



Then, she asked students to get into groups of four and for a few minutes, look at each other's post-it notes and the questions that people have asked about this graph. She then gave them another worksheet with statements that students were asked to decide as a group whether they agreed with them or not. The next activity students should do as a group was to decide which of the four statements is the best description of the graph and explain their answer (say why). She emphasised that students should compromise if they disagreed and that they should try and persuade each other about their view. As students worked on the second part of their worksheet she went around the groups, prompted them for arguments and for counter-arguments. She also provided positive feedback on students' ability to justify their answers.

As a final activity, she asked one student from each group to move to the group next to them in order to compare answers. If their answers were the same then students should compare their justifications and if they had different answers they should discuss why they disagreed. This activity went on for about 2 minutes during which Amy was asking and comparing answers with students in one group at the front of the room. As a plenary, she asked for each group to state which statement they thought was the best and why before she provided her own evaluative judgment saying that D was the best statement. The way she phrased which was the best statement was interesting as she said that none was wrong although statement D was better than the rest since it was more accurate and identified the fact that not every point fitted the pattern.

On the whole, this lesson provided many opportunities for engagement with evaluative talk, as one of the objectives of the lesson was to 'evaluative if claims made using the data are plausible or not' (lesson plan). For instance, the last activity provided opportunities for the use of 'Evaluation', 'Compare & Contrast', 'Justification' and 'Counter-Argument' as students needed to compare the statements and state which is best and why, providing justifications to support their answers. Moreover, 'Prompts for Argument' and 'Prompts for

Evaluation' would also be expected to be present. The analysis of classroom talk was similar to the expected epistemic operations from this lesson, with a particular emphasis placed on evaluative talk. Nonetheless, 'Counter-Argument' or 'Prompts for Counter-Argument' were not used although opportunities for the discussion of differing views were provided by the structure of the activities and the worksheet provided.

Analysing & Interpreting Data (2)

(a) The pupils tried to describe the pattern. Look at what they said below and complete each box with a YES or a NO to answer the question at the top.

What the pupils said	Does the statement mention both factors? YES or NO	Does the statement describe the general pattern? YES or NO	Does the statement indicate that data from some individuals does not fit the pattern? YES or NO
(a) One pupil had the most breaths and she also had the highest pulse rate.			
(b) All the people with a high breath rate had a high pulse rate.			
(c) The higher your breathing rate, the greater the pulse rate.			
(d) On the whole, those people with a higher breathing rate had a higher pulse rate.			

(b) Which of the four statements in the table is the best description? Explain your answer.

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Lesson plan

Coursework Support: Data Analysis | Evaluating Data

Aims

The purpose of this exercise is to:

- Provide an opportunity for pupils to interpret, evaluate and discuss experimental data;
- Encourage pupils to generate arguments for why the conclusions drawn from the experimental data may or may not be plausible explanations.

Learning Objectives

The learning objectives of this lesson are to:

- Interpret data presented in graphs.
- Argue how the data may support certain claims.
- Evaluate if claims made using the data are plausible or not.
- Justify any data that do not conform to an overall pattern.

Teaching Points

Pupils are presented with results from an experiment – results about the relationship between people's pulse rate and the number of breaths that they take. Pupils are then asked to evaluate the conclusions provided and consider the factors which make one better than the others.

This lesson is designed to assist pupils in drawing conclusions and evaluating their own data that they may have collected as part of the data analysis / investigation coursework. The lesson can of course be taught when you wish, but it may be useful to teach this lesson after they have collected their data and drawn their graph(s), but before they develop their conclusions and evaluations.

It should be made clear to pupils that the data presented in this activity is unrelated to the data they have collected as a part of their coursework, but the principles of evaluating the graph and data can be applied to their own work.

Teaching Sequence

Starter: **(10 mins)**

It may be useful to introduce the task by first reviewing what the graph represents. For some groups you may want to give a broad introduction about sports and the link between pulse rate and breathing rate.

Distribute the first activity sheet. Explain to pupils that the graph is produced from a set of data collected for pulse rates and breathing rates. At this point you might want to explain what these variables are and how they are collected by getting one or all of your pupils measuring their own pulse and breathing rates.

Ask pupils to spend 2-3 minutes looking at the graph individually. During this time they should note down on a post-it note what pattern there is in the graph and any questions they have about the graph.

Main Activity: **(25 mins)**

Now arrange pupils into groups of 4. Ask them to begin by sharing the patterns they have noted and any questions they might have about the graph. Give them no more than **5 minutes** to do this.

Next distribute the second activity sheet (1 per group) and ask the groups to complete the table. Explain that on the table, the left hand column consists of examples of statements made by pupils from the other class and their task is to indicate whether or not they agree with these statements.

Once they have completed the table, ask pupils to complete the next part of the activity. They will need to select which statement they agree with the most and why. It is important to emphasis that they need to explain their reasons for selecting that statement. Altogether, allow about **20 minutes** for the completion of the table and the selection of the best explanation.

Plenary: **(15 mins)**

Ask the pupils to discuss their group's decision on the best explanation and prepare to present their ideas. They should spend about **5 minutes** on the task.

Conduct the plenary session with either each group presenting to the whole class, or use 'envoys' where one pupil from each group moves to another group to compare the conclusions their group has arrived at with the other group.

With more able groups, where there are differences of opinion, encourage pupils to provide justifications for how the other group's point of view is not valid. In other words, encourage the pupils to provide rebuttals to the other group's opinion. Their rebuttals should be based on evidence that can be referred back to in the graph.

Finish by going over the table with the class, explaining that the answers should be:

Statement	Both Factors?	General Pattern?	Anomalous Data?
(a)	YES	NO	NO
(b)	YES	YES	NO
(c)	YES	YES	NO
(d)	YES	YES	YES

(Osborne et al., 2004b, IDEAS pack)

APPENDIX J

A summary of Amy's use of epistemic operations in each of the 12 lessons observed (L1, L5, L7 and L12 are the argumentation lessons)

Epistemic operations ***performed*** by Amy

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
Analogies & Metaphors	0	6	0	2	2	1	0	0	0	5	2	0
Argument	4	3	0	2	3	0	2	0	0	6	0	3
Compare and contrast	0	3	0	1	1	2	4	1	0	5	0	2
Counter-argument	1	1	0	0	5	0	0	0	0	1	0	0
Definition	1	2	1	0	1	1	0	1	0	2	2	5
Description	5	12	4	5	4	9	7	6	5	8	9	5
Evaluation	8	18	35	7	18	25	16	8	10	15	29	15
- IRE	6	12	25	4	10	17	11	5	6	4	11	8
Exemplification	5	9	0	6	4	9	3	3	7	1	4	2
Explanation	0	8	2	0	6	1	6	2	5	7	1	4
Generalisation	10	5	1	1	13	5	6	4	2	4	4	6
Justification	5	20	21	15	16	14	14	8	2	19	17	22
- Procedural	1	3	4	9	6	5	2	3	1	4	1	9
- Reflective	3	2	2	1	2	1	5	3	0	1	3	4
- Content-based	1	14	15	5	8	9	7	2	1	14	13	9
- 'why'	24	8	2	6	29	11	23	0	0	4	6	21
Modelling	0	0	0	0	0	0	0	0	1	0	3	1
Prediction	0	0	1	0	0	0	0	0	0	1	1	0
Provides evidence	10	24	20	17	21	39	4	20	11	26	19	8

Epistemic operations ***prompted*** by Amy

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
Prompts for Argument	14	2	0	5	13	6	15	1	0	1	0	11
Prompts for classification	0	0	8	0	6	0	5	0	0	2	0	0
Prompts for Comparison	0	3	2	1	0	0	8	0	0	0	0	4
Prompts for Counter-Argument	7	0	0	2	1	0	3	0	0	0	0	2
Prompts for Definition	0	4	0	0	1	0	1	0	4	4	2	3
Prompts for Description	0	0	1	1	0	5	0	3	1	0	4	9
Prompts for Evaluation	6	3	1	1	12	12	17	3	1	2	3	18
Prompts for Evidence	10	20	24	4	10	21	15	18	20	24	19	10
Prompts for Justification	20	8	0	3	17	9	11	0	1	3	3	11
Prompts for Prediction	2	0	1	1	0	0	0	0	0	0	8	0

APPENDIX K

James' written assessment of the four students interviewed in Case Study 1

S1 female	S1 seems disinterested; she has difficulty engaging with the learning. This is manifest in her unwillingness to make a contribution to discussion work. When pressed she demonstrates the potential to do very well in science. In group work, S1 tends to be off task. She is able to handle apparatus more precisely and her understanding of argument is more sophisticated but again, her progress is limited by her work rate rather than her ability. S1 needs to show a willingness to engage with the learning, she needs to listen more carefully to instructions and play a full part in group work and whole class discussion.
S2 female	S2 seems to enjoy the subject, listening carefully to instructions and getting on with the job when the task is set. She is more willing to ask questions when stuck. Her practical skills are becoming more sophisticated and she is able to handle apparatus with a greater degree of precision. Written work shows some care and attention to detail. S2 plays an active part in group work where she is willing to share her ideas as well as listen to other people. She is increasingly able to present argument in a structured way. S2 needs to consolidate her own understanding of key ideas through the use of active revision techniques like transforming information into diagrams or flow charts. She also needs to develop alternative strategies for getting unstuck, apart from asking the teacher.
S3 male	S3 grasps ideas with ease and can follow a train of thought to its logical conclusion. He can be focused, take the lead and drive the progress of a group with his vision of the solution to a problem. S3 can express himself concisely and handle apparatus with confidence. His appreciation of how to structure an argument is much more sophisticated, S3 struggles to demonstrate this focus with written tasks, some group work tasks and home learning assignments. Written work is characterized by a sloppy lack of care and attention to detail and an urgency to do the job as quickly as possible rather than properly. He needs to be more consistent regarding his general attitude, particularly his appreciation of the importance of listening and staying on task during group work assignments. S3 needs to consolidate his progress by revising for assessments using a variety of active techniques to do so. These might include note taking and transforming information into diagrams or flow charts. In group work he needs to be focused, at all times, on the task in hand.
S4 male	S4 quickly grasps ideas and can follow a train of thought to its logical conclusion. He is focused, takes the lead and drives the progress of a group with his vision of the solution to a problem. S4 can express himself clearly and concisely. His practical skills include an ability to handle apparatus with an impressive degree of precision. He can analyse data and evaluate both data and methods in a sophisticated way. Home learning assignments demonstrate a similar commitment to success. S4 needs to read around the subject, particularly science in the news, to develop his perspective on science as an evolving body of knowledge. He also needs to develop his extended writing so that he can express more depth of understanding by linking ideas together.