EXPLORING THE INFLUENCE OF A SCIENCE CONTENT COURSE INCORPORATING EXPLICIT NATURE OF SCIENCE AND ARGUMENTATION INSTRUCTION ON PRESERVICE PRIMARY TEACHERS' VIEWS OF NATURE OF SCIENCE

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ABSTRACT

There exists a general consensus in the science education literature around the goal of enhancing students' and teachers' views of nature of science (NOS). An emerging area of research in science education explores NOS and argumentation, and the aim of this study was to explore the effectiveness of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS.

A constructivist perspective guided the study, and the research strategy employed was case study research. Five preservice primary teachers were selected for intensive investigation in the study, which incorporated explicit NOS and argumentation instruction, and utilised scientific and socioscientific contexts for argumentation to provide opportunities for participants to apply their NOS understandings to their arguments.

Four primary sources of data were used to provide evidence for the interpretations, recommendations, and implications that emerged from the study. These data sources included questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts. Data analysis involved the formation of various assertions that informed the major findings of the study, and a variety of validity and ethical protocols were considered during the analysis to ensure the findings and interpretations emerging from the data were valid.

Results indicated that the science content course was effective in enabling four of the five participants' views of NOS to be changed. All of the participants expressed predominantly limited views of the majority of the examined NOS aspects at the commencement of the study. Many positive changes were evident at the end of the study with four of the five participants expressing partially informed and/or informed views of the majority of the examined NOS aspects.

A critical analysis of the effectiveness of the various course components designed to facilitate the development of participants' views of NOS in the study, led to the identification of three factors that mediated the development of participants' NOS views: (a) contextual factors (including context of argumentation, and mode of argumentation), (b) task-specific factors (including argumentation scaffolds, epistemological probes, and consideration of alternative data and explanations), and (c) personal factors (including perceived previous knowledge about NOS, appreciation of the importance and utility value of NOS, and durability and persistence of pre-existing beliefs). A consideration of the above factors informs recommendations for future studies that seek to incorporate explicit NOS and argumentation instruction as a context for learning about NOS.

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GLOSSARY

Argumentation: A type of informal reasoning that in its simplest form consists of a claim, evidence, and justification.

Argumentation scaffold: A written or verbal prompt that encourages participants to engage in argumentation.

Contextualised NOS instruction: An approach to teaching NOS that relates and integrates relevant aspects of NOS to the science content being examined.

Decontextualised NOS instruction: An approach to teaching NOS that incorporates generic activities and/or instruction about various NOS aspects that are not directly related or linked to the science content being examined.

Epistemological probe: A written or verbal prompt that orients participants' attention to relevant NOS aspects highlighted in a task, or focuses the participants' attention on a question designed to draw on their epistemological knowledge or reasoning.

Explicit argumentation instruction: An approach to teaching argumentation that utilises direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function, and application of arguments, and the criteria used to assess the validity of arguments.

Explicit NOS instruction: An approach to teaching NOS that deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion and questioning.

Implicit NOS instruction: An approach to teaching NOS that is underpinned by the view that an understanding of NOS will result from engaging learners in inquiry-based activities, without the addition of deliberately-focused (explicit) NOS instruction.

Nature of science (NOS): Epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992).

Scientific contexts for argumentation: Contexts for argumentation that are concerned with the application of scientific reasoning to enable an understanding of the justification for hypotheses, the validity and limitations of scientific evidence, and the evaluation of competing models and theories (Giere, 1979).

Socioscientific contexts for argumentation: Contexts for argumentation that are concerned with the application of scientific ideas and reasoning to an issue, and also invoke a consideration of moral, ethical and social concerns (Osborne, Erduran & Simon, 2004a).

STATEMENT OF ORIGINAL AUTHORSHIP

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made.

Signature: ………………………………………

Date: ………………………………………

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CHAPTER 1 – INTRODUCTION

1.1 Rationale

> …science education needs to diversify its emphasis beyond focusing on canonical abstract ideas, and place greater emphasis on the nature of science and the way it operates. It needs to include a more sophisticated version of scientific investigation and the concepts of evidence, and an explicit focus on capabilities such as analytic thinking and problem solving, communication, and creativity. (Tytler, 2007, p. 31)

There exists a general consensus in the science education literature around the goal of enhancing students' and teachers' views of nature of science (NOS). Indeed this goal has been documented in the literature for at least the past 85 years (Abd-El-Khalick, Bell, & Lederman, 1998), and has been the focus of numerous research efforts for over 50 years (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992). Many reasons have been cited by science education researchers and reform organisations for developing students' and teachers' understanding of NOS, with perhaps the most fundamental reason positing that an understanding of NOS is necessary for achieving scientific literacy (American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council, [NRC] 1996; Tytler, 2007).

An understanding of NOS has been found to aid students and teachers in making sense of cultural, social, political and moral issues related to science (Driver, Leach, Millar, & Scott, 1996; Wolfer, Robinson, Mason, Heppert, & Ellis, 2001); and students' ideas about NOS may also determine how they behave in classroom situations, such as those that occur during the interpretation of practical activities in the science classroom (Leach, Millar, Ryder, & Sere, 2000).

NOS is commonly defined as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992), and incorporates characteristics such as the empirical, tentative, subjective, creative, and social NOS. Despite the extensive amount of research that has been conducted in the field of NOS and the prominence of this important component of scientific literacy in the reform documents, many studies continue to show that students and teachers fail to express informed views of NOS (Duschl, 1990; Lederman, 1992).

1.1.1 NOS research

An analysis of recent research trends in the field of NOS has highlighted two broad areas of interest, both of which are concerned with instructional approaches that aim to improve participants' views of NOS - explicit and implicit NOS instructional approaches, and contextualised and decontextualised NOS instructional approaches. Implicit instructional approaches to teaching NOS are underpinned by the view that an understanding of NOS will result from engaging students in inquiry-based activities, without the addition of deliberately-focused (explicit) NOS instruction. A review of early and recent studies that have utilised an implicit instructional approach (e.g., Barufaldi, Bethel, & Lamb, 1977; Meichtry, 1992; Moss, Abrams, & Robb, 2001; Riley, 1979; Sandoval & Morrison, 2003; Scharmann & Harris, 1992; Schwartz, Lederman, & Thompson, 2001; Trembath, 1972), indicated that participants' views of NOS were not substantially developed as a result of implementing this type of instructional approach.

An explicit NOS instructional approach deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion and questioning. This type of instructional approach is based on the assumption that NOS instruction should be planned for, and implemented in the science classroom as a central component of learning, not as an auxiliary learning outcome. An analysis of the findings reported in many reviewed studies (e.g., Abd-El-Khalick & Lederman, 2000b; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Morrison, & Roth McDuffie, 2006; Carey & Strauss, 1968, 1970; Hanuscin, Akerson, & Phillipson-Mower, 2006; Jones, 1969; Khishfe & Abd-El-Khalick, 2002; Lederman, Lederman, Kim & Ko, 2006; Shapiro, 1996; Smith, Maclin, Houghton, & Hennessey, 2000), provides evidence of the effectiveness of explicit approaches to NOS instruction to aid in promoting informed understandings of NOS.

A contextualised NOS instructional approach relates and integrates relevant aspects of NOS to the science content being examined, whereas a decontextualised NOS instructional approach incorporates generic activities and/or instruction about various NOS aspects that are not directly related or linked to the science content being examined. Findings from the majority of studies conducted in this area (e.g., Brickhouse, Dagher, Letts IV, & Shipman, 2000; Clough & Olson, 2001; Johnston & Southerland, 2002; Khishfe & Lederman, 2006; Schwartz & Lederman, 2002) provide some evidence of the effectiveness of a contextualised approach to NOS instruction to aid in promoting informed understandings of NOS.

1.1.2 Argumentation research

A related body of research in science education is concerned with argumentation in science. Various science educators have proposed that an understanding of argumentation contributes to scientific literacy. For example, engagement in argumentative practices provides students and teachers with the ability to think scientifically about everyday issues, and critically analyse scientific reports (Newton, Driver, & Osborne, 1999; Osborne, Erduran, & Simon, 2004a); and argumentation strategies are recognised as a central tool for evaluating and justifying knowledge claims (Duschl, Ellenbogen, & Erduran, 1999). Argument construction is a daily aspect of scientists' work (Yerrick, 2000), and an appreciation of the argumentative nature of science enhances students' and teachers' understanding of the role of argument in constructing the link between data, claims and warrants (Osborne et al., 2004a). Argumentation within the scientific community also provides a quality control for science (Kuhn, 1992) and argumentation is a central component of both doing science and communicating scientific knowledge (Lemke, 1990).

Some scholars have proposed that argumentation is central to the philosophy of science, where knowledge is viewed as socially constructed. This knowledge emerges as a result of observation and argumentation, where the function of argument is to provide a link between the speculation of scientists and the evidence available (Newton et al., 1999). Thus, argumentation can be considered to be an essential feature of science learning. The scientific community has its own unique language and epistemological assumptions that differ from other ways of knowing (Duschl et al., 1999) and students and teachers should be expected to be enculturated into this community.

An examination of previous studies conducted in the field of science education that have utilised argumentation in their design has highlighted the following three general findings. First, students generally have poor argumentation skills with specific difficulties such as ignoring data and warrants, introducing inferences and re-interpretations, jumping to conclusions, and an inability to evaluate counter-evidence commonly reported (Chinn & Brewer, 1998; Driver, Newton, & Osborne, 2000; Kortland, 1996; Kuhn, 1991; Perkins, Faraday, & Bushey, 1991; Perkins & Salomon, 1989; Zeidler, 1997; Zeidler, Walker, Ackett, & Simmons, 2002).

Second, most classrooms are teacher dominated, with students given few opportunities to learn about, or engage in argumentation (Cross & Price, 1996; Geddis, 1991; Newton et al., 1999). Third, factors such as age and previous knowledge may influence argumentation skills (Kuhn, 1991; Means & Voss, 1996; Perkins & Salomon, 1989), and finally the relationship between conceptual knowledge and argumentation is complex and the subject of many current studies (e.g., Bell & Linn, 2000; Hogan, 2002; Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl., 1997; Jimenez-Aleixandre & Pereiro-Munoz, 2002; Kortland, 1996; Tytler, Duggan, & Gott, 2001; Zohar & Nemet, 2002).

An important area of recent research in the field seeks to investigate the relationship between explicit instruction in argumentation and students' skills and/or quality of argumentation (e.g., Bell & Linn, 2000; Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl, 2000; Osborne et al., 2004a; Yerrick, 2000; Zohar & Nemet, 2002). A general recommendation emerging from recent studies in this area supports the notion that explicit instruction in argumentation is a necessary prerequisite for enabling the development of students' skills and/or quality of argument. Explicit instruction in this context refers to the direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function, and application of arguments, and the criteria used to assess the validity of argument.

Two important findings were identified from an analysis of research conducted in this area. First, an important trend which emerged from the analysis of these studies was the impact of conceptual knowledge on students' abilities to formulate arguments. Many of the studies that incorporated explicit argumentation instruction and reported improvements in students' argumentation abilities stressed the importance of integrating relevant conceptual knowledge when formulating arguments.

Another trend that emerged from an analysis of these studies was the impact of context on students' abilities to formulate arguments. Osborne et al. (2004a) have highlighted that two distinct contexts for argumentation in science exist, namely, scientific and socioscientific contexts. Scientific contexts for argumentation are concerned with the application of scientific reasoning to enable an understanding of the justification for hypotheses, the validity and limitations of scientific evidence, and the evaluation of competing models and theories (Giere, 1979). Socioscientific contexts for argumentation are concerned with the application of scientific ideas and reasoning to an issue, and also invoke a consideration of moral, ethical and social concerns. Engaging students in argumentation in both contexts is deemed necessary to ensure they are made aware of the differing considerations each type of argument presents.

Osborne et al.'s (2004a) research which focused on enhancing the quality of teachers' and students' argumentation was the only empirical study identified in the literature that examined argumentation in both scientific and socioscientific contexts. Implications drawn from this study suggest that students need to be explicitly guided in developing and applying skills of argument in both scientific and socioscientific contexts, and that the application of relevant conceptual knowledge may be needed (particularly in scientific contexts) to ensure students are able to engage in argumentation effectively.

1.1.3 NOS and argumentation research

An emerging area of research explores NOS and argumentation. A search of the literature revealed nine studies that have been conducted in this area. Four of these studies have been conducted in scientific contexts (Bell & Linn, 2000; Kenyon & Reiser, 2006; Sandoval & Millwood, 2005; Yerrick, 2000), four studies were conducted in socioscientific contexts (Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Walker & Zeidler, 2004; Zeidler, Walker et al., 2002), and one study was conducted in a historical context (Ogunniyi, 2006).

Recent research has suggested that a possible relationship exists between learners' views of NOS and scientific argumentation (Bell & Linn, 2000; Kenyon & Reiser, 2006; Kuhn & Reiser, 2006; Sampson & Clark, 2006; Sandoval & Millwood, 2005; Yerrick, 2000). Sampson and Clark (2006) propose that the epistemological commitments learners hold influence how they participate in scientific argumentation, and suggest that improving learners' skills of argument will involve changing their epistemological views in addition to developing pedagogical practices that support and promote argumentation in the classroom. Kuhn and Reiser (2006) hold a similar view and propose that learners' epistemological ideas may influence how they participate in scientific argumentation. Recent studies conducted by Kenyon and Reiser (2006) and Sandoval and Millwood (2005) are underpinned by the assumption that learners' views of NOS influence how they engage in scientific argumentation. Results from these studies suggest a possible relationship between learners' views of NOS and their engagement (or lack of engagement) in scientific argumentation.

Other researchers have viewed the relationship between NOS and scientific argumentation in a slightly different manner. Studies conducted by Bell and Linn (2000) and Yerrick (2000) are guided by the assumption that engaging learners in the process of argumentation may improve their understandings of NOS. Results from these studies provide some evidence to suggest that engaging learners in scientific argumentation may lead to improvements in their views of NOS.

Research conducted in socioscientific contexts has also highlighted possible links between learners' NOS views and their engagement in argumentation in socioscientific contexts (Kolsto et al., 2006; Lewis & Leach, 2006; Sadler et al., 2004; Walker & Zeidler, 2004; Zeidler et al., 2002; Zeidler et al., 2005), although one study (Bell & Lederman, 2003) failed to find a relationship between participants' views of NOS and their socioscientific reasoning. Zeidler et al. (2005) propose that students' views of NOS influence the manner in which they view, cite and use evidence that may support or oppose their pre-existing beliefs about particular socioscientific issues. They recommend that students need to be provided with guidance in applying their NOS understandings during the decision-making process, and learn to critically evaluate scientific claims, some of which may oppose their pre-existing views. Research conducted by Bell and Lederman (2003) and Walker and Zeidler (2004) highlights the importance of providing guidance to enable learners to apply their views of NOS to their reasoning in socioscientific contexts.

Kolsto, Bungum, Arnesen, Isnes, Kristensen, Mathiaseen, et al., (2006) also support the view that understandings of NOS are needed to allow students to engage with socioscientific issues. Lewis and Leach (2006) have highlighted the importance of providing explicit NOS instruction to enable students to effectively engage in socioscientific reasoning. They suggest that classroom instruction directed at developing students' argumentation skills, and moral and ethical reasoning abilities, would allow students to engage in socioscientific reasoning more effectively. Further studies are needed to examine the influence of these factors on learners' views of NOS and/or argumentation in socioscientific contexts.

A consideration of the findings and trends identified in the nine empirical studies that have explored NOS and argumentation highlight the importance of incorporating both explicit argumentation instruction and explicit NOS instruction in studies that aim to develop learners' views of NOS. Learners need to recognise the relevancy of applying their understandings of NOS to their arguments to ensure that the arguments they develop are informed by epistemological considerations, and not narrowly focused on personal factors or pre-existing views. On the basis of these findings, the tentative claim could be made that integrating explicit NOS and argumentation instruction in the science classroom, and allowing learners to apply their views of NOS to their reasoning and arguments in scientific and/or socioscientific contexts, may lead to improvements in their views of NOS.

1.1.4 Summary

A consideration of the broad literature base examined in this thesis informs the aims and design of this study. A review of NOS research outlined in Chapter 2 will provide evidence to support the adoption of an explicit, contextualised approach to NOS instruction to aid in developing participants' views of NOS. Implementing this instruction within a science content course will be recommended to allow contextualised NOS instruction to occur, and preservice primary teachers are chosen as ideal participants for the study as they have a pivotal role in providing NOS instruction to their students.

A review of argumentation research outlined in Chapter 3 will provide evidence to support the adoption of an explicit argumentation instructional approach to aid in developing participants' skills and/or quality of argumentation. Engaging participants in argumentation in both scientific and socioscientific contexts will also be recommended as recent findings indicate a possible relationship between the context of argumentation and the development of participants' skills and/or quality of argumentation.

A review of emerging research exploring NOS and argumentation outlined in Chapter 4 will provide evidence to suggest that explicit instruction in both NOS and argumentation is necessary to aid in developing participants' views of NOS. It will also be proposed that participants need to be given the opportunity to apply their views of NOS to their reasoning and arguments in scientific or socioscientific contexts.

1.2 Research aim

The aim of this study is to explore the influence of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS. The research questions guiding this exploratory study are:

1a. What are preservice primary teachers' initial views of the examined aspects of NOS?

1b. Do their views of these aspects of NOS change over the course of the intervention?

2. What is the influence of the various course components implemented during the study, on preservice primary teachers' views of the examined aspects of NOS?

3. What factors mediated the development of preservice primary teachers' views of the examined aspects of NOS?

This study will incorporate a classroom intervention that has been designed to include explicit, contextualised NOS instruction within a science content course. The course will utilise scientific and socioscientific contexts for argumentation, to provide opportunities for preservice primary teachers to apply their NOS understandings to their arguments. Explicit argumentation instruction will also be implemented throughout the classroom intervention.

The research strategy employed in this study will be case study research. The study will be conducted with five preservice primary teachers in a single-semester science content course. Six course components will be implemented in the study, designed to aid in the development of participants' views of NOS. These course components are (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project.

Four primary sources of data will be used to provide evidence for the interpretations, recommendations and implications emerging during the course of the study. These data sources will include questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts. Data analysis will be conducted at the conclusion of the study, and a variety of validity and ethical protocols will be considered during the analysis to ensure the findings and interpretations emerging from the data are valid.

1.3 Significance of the study

This study will make a unique contribution to the field as no studies have been identified in the literature that have investigated NOS and argumentation in both scientific and socioscientific contexts, nor have studies implementing explicit instruction in NOS and argumentation in both of these contexts been reported. Additionally, very few studies have been conducted with preservice primary teachers in this area.

Specifically, this study will critically analyse the effectiveness of various course components designed to develop participants' views of NOS, and identify and investigate the various factors that mediated the development of participants' NOS views. Information obtained from these analyses will add to the emerging body of research conducted in the area of NOS and argumentation, and will inform the design of future studies that seek to incorporate explicit NOS and argumentation instruction as a context for learning about NOS.

From a wider educational perspective, the classroom strategies advocated in this study will inform the pedagogical practices of preservice and inservice science teachers wishing to develop their students' views of NOS. As an informed understanding of NOS has been cited by science education researchers and reform organisations (e.g., American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council, [NRC] 1996; Tytler, 2007) as a crucial requirement for developing scientifically literate students, it is imperative to provide science teachers with pedagogical tools and strategies to help meet this goal. This study will help to address this goal.

1.4 Structure of the thesis

This chapter provided a rationale for exploring NOS and argumentation in this study. The aim of the study was outlined in this chapter and this aim will be addressed by attempting to answer the three research questions guiding this study. Chapter 2 will provide a comprehensive overview of research conducted in the field of NOS. The purpose of this review is to situate the study within the broader context of NOS research and to critically analyse recent NOS teaching approaches designed to develop or improve students' and teachers' views of NOS. An overview of research in the field of argumentation, with a specific focus on studies conducted in science education, will be provided in Chapter 3. The purpose of this review is to situate the study within the broader context of argumentation research and to critically analyse the various modes and contexts of argumentation instruction.

Chapter 4 will provide a detailed overview of an emerging area of research exploring NOS and argumentation. The purpose of this review is to identify trends in the current research base, and provide evidence to support the inclusion of explicit NOS and argumentation instruction in scientific and socioscientific contexts, to aid in developing students' and teachers' views of NOS. The contribution of this study will be outlined at the end of the chapter. A comprehensive overview of the research design developed to address the aim of the study will be provided in Chapter 5. The purpose of this chapter is to provide a justification for the research design employed in the study.

Chapter 6 will provide a comprehensive analysis of participants' pre- and post-intervention views of the examined aspects of NOS. Findings from this analysis will provide evidence to address the first research question. The purpose of this chapter is to explore the change (or lack thereof) in participants' views of the examined NOS aspects and to identify trends in the data pertaining to the development of participants' NOS views.

A comprehensive analysis of the influence of the six course components implemented during the study on participants' views of the examined NOS aspects will be provided in Chapter 7. Findings from this analysis will provide evidence to address the second research question. The purpose of this chapter is to evaluate the influence of the course components on participants' views of the examined NOS aspects and to identify trends in the data pertaining to the development of participants' NOS views. Chapter 8 will provide a critical analysis of the various contextual, task-specific, and personal factors mediating the development of participants' views of the examined NOS aspects. Findings from this analysis will provide evidence to address the third research question.

Chapter 9 will provide a summary of the study, followed by a discussion of the major conclusions emanating from the study and implications for future studies. Limitations of the study will also be outlined.

CHAPTER 2 – NATURE OF SCIENCE RESEARCH

2.1 Introduction

This chapter will provide a comprehensive overview of research conducted in the field of NOS. The purpose of this review is to situate this study within the broader context of NOS research, and critically analyse recent NOS teaching approaches designed to develop or improve students' and teachers' views of NOS. This review will provide evidence to support the adoption of an explicit, contextualised approach to NOS instruction to aid in developing students' and teachers' NOS views.

The chapter will commence with an overview of the theoretical framework guiding this study, which stems from a cultural psychological view of knowledge. The following section will examine research conducted in the field of NOS. General definitions and characteristics of NOS will be outlined, followed by a historical review of previous studies. A detailed assessment of 20th century NOS studies will then be discussed, followed by an examination of important recent trends in the field. A discussion of methodological implications that have evolved from previous studies will also be outlined, and the chapter will conclude with a summary of the major findings from the literature.

2.2 Theoretical framework

The theoretical framework that informs this study is derived from a cultural psychological view of knowledge. Cultural psychology emerged during the second half of the 20th century in response to the limitations many scholars experienced whilst trying to work within the dominant framework of cross-cultural psychology. Cross-Cultural psychology is guided by the laws and methodology of the natural sciences. As such, psychologists working within this paradigm attempt to use experimental procedures in order to understand human actions and practices. As early as 1880, the German psychologist, Wilhelm Wundt, identified limitations in using the methods of the scientific paradigm to study human action and suggested that a second psychology existed which was underpinned by a paradigm at odds with the natural sciences. Wundt’s second psychology recognised the central role of culture and history on human psychological processes (Cole, 1996).

A little over forty years later, the Soviet psychologist, Lev Vygotsky, drawing on the work of Engels, developed a dialectical approach to the analysis of human higher psychological functioning. This approach acknowledged the impact of mankind on nature and allowed for the development of a second psychology, termed cultural psychology, which was able to coexist with the dominant paradigm of the natural sciences. Vygotsky (1978, p. 57) proposed that “the internalisation of socially rooted and historically developed activities is the distinguishing feature of human psychology, the basis of the qualitative leap from animal to human psychology.” He emphasised the important connection between human artefacts and cognition.

One of the main proponents of modern cultural psychology, Michael Cole, describes the cultural psychological approach to understanding human action in simple terms: “when we study human development we must make the study of surrounding social practices part and parcel of our inquiry” (Cole, 1996, p. xiv). He has developed a set of seven characteristics which define a cultural psychological view of knowledge:

> (a) it emphasises mediated action in context; (b) it insists on the importance of the ‘genetic method’ understood broadly to include historical, ontogenetic, and microgenetic levels of analysis; (c) it seeks to ground its analysis in everyday life events; (d) it assumes that mind emerges in the ‘joint’ mediated activity of people. Mind, then, is in an important sense, “co-constructed” and distributed; (e) it assumes that individuals are active agents in their own development but do not act in settings entirely of their own choosing; (f) it rejects cause-effect, stimulus-response, explanatory science in favour of a science that emphasises the emergent nature of mind in activity and that acknowledges a central role for interpretation in its explanatory framework; (g) it draws upon methodologies from the humanities as well as from the social and biological sciences. (1996, p. 104)

Constructivism is a learning theory which is aligned with the basic tenets of cultural psychology. A constructivist perspective on learning assumes that knowledge is actively constructed by the learner while drawing on previous understandings and explanations (Driver, Asoko, Leach, Mortimer, & Scott, 1994). This view of learning lies in opposition to a transmissive perspective which assumes that knowledge is simply transferred from knower to learner. This traditional view of learning is guided by an objectivist philosophy which views learning as a linear process where difficult problems are broken down into simpler parts to enable learning to take place.

Constructivism can be viewed from a number of different perspectives. One of these perspectives is known as radical constructivism where the primary focus of study is cognition and the individual (von Glasersfeld, 1984). Staver (1998, p. 504) extends this work and asserts that "cognition's purpose is to serve the individual's organisation of his or her experiential world; cognition's purpose is not the discovery of an objective ontological reality." Radical constructivists believe that individuals develop their own personal theories about the world as a result of their daily physical experiences. Other theorists have described this brand of constructivism as 'personal constructivism' or 'cognitive constructivism.'

Social constructivists view the construction of knowledge in a different manner. Language plays a central role in this perspective as social constructivists believe that human knowledge is constructed through a process of social dialogue. The work of Vygotsky (1978) underpins this perspective and recognises that learners collaboratively construct knowledge during a negotiation process. Social constructivists stress the importance of the "dialectical interplay between nature and history, biology and culture, the lone intellect and society" (Roth, 1994, p. 15). Thus, learning can be thought of as a process where individuals are initiated into a particular culture by more able others. The activities of the culture provide its members with cultural tools and conventions which allow them to make sense of new ideas.

A theoretical perspective emanating from the work of social constructivists recognises the situated nature of cognition which incorporates not only the individual, social and cultural contexts, but also the physical context of the individual (Roth, 1994). This approach to learning is referred to as sociocultural theory and this framework is complementary to the aforementioned theories which stress the importance of social and cultural contexts. Sociocultural theorists posit that learning can be viewed as the acquisition of the necessary knowledge and skills to enable an individual to become a member of a community of practice. The notion of ‘community of practice’ has received widespread recognition in recent times as an important analytical tool for understanding how both individuals and groups conceptualise knowledge. Brown, Collins, and Duguid (1989) further develop these ideas by introducing the concept of authentic activities, which are described as the ordinary practices of the culture. These activities are scaffolded by the culture in which they take place, and are constructed through the social interactions of the members of the culture.

From a science education perspective, viewing scientific knowledge as socially constructed differs from a traditional, empiricist perspective of discovering factual knowledge by employing a strict ‘scientific method.’ A sociocultural perspective on science education proposes that “learning science (…) involves being initiated into the ideas and practices of the scientific community and making these ideas and practices meaningful at an individual level” (Driver et al., 1994, p. 6). Lemke (2001) supports this notion and states that the study of the world from a scientific perspective cannot be separated from the social environment of the scientific community.

The basic set of assumptions which have been outlined in this section will inform and guide the design, implementation and analysis of this study. The following section will examine research conducted in the field of NOS. It will commence with an overview of the definitions and characteristics of NOS utilised in the science education literature.

2.3 Nature of science – Definitions and characteristics

The phrase 'nature of science' (NOS) has been defined by scholars in a variety of ways. Although no universal definition exists in the literature, a commonly utilised definition is provided by Lederman (1992) who refers to NOS as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development. Other science educators refer to NOS as one's understanding about the social practices and organisation of science, and how scientists collect, interpret, and use data to guide further research (Ryder, Leach, & Driver, 1999). McComas et al. describe NOS as:

> …a fertile, hybrid arena which blends aspects of various social studies of science including the history, sociology and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours. (1998, p. 4)

It is important to distinguish 'knowledge about science' from 'scientific knowledge.' The former is concerned with the epistemology of science, and the way that science functions; as opposed to the later which is focused on understanding natural phenomena, including both the processes and content of science (Driver et al., 1996). As such 'knowledge about science' is more directly related to the field of NOS than 'scientific knowledge.'

Although some debate exists in science education literature regarding a common definition of NOS, an important point is made by McComas et al. who state:

> One of the central responsibilities of science teachers is to provide an accurate description of the function, processes and limits of science rather than to engage students in the somewhat arcane arguments that occur among philosophers of science. At the level of description, there is significant consensus regarding the nature of science. (1998, p. 6)

Therefore, although the three definitions of NOS provided in the previous paragraphs are slightly different, they are similar in the respect that they all recognise that NOS is concerned with epistemological assumptions that underpin scientific processes, such as recognising that observations and hypotheses are theory-laden, and that scientific knowledge is influenced by social and cultural factors.

The terms nature of science (NOS), epistemology of science, and nature of scientific knowledge are used by various researchers studying students' and teachers' 'knowledge about science.' This thesis will adopt the term 'NOS' to describe these understandings. Many of the studies reviewed in this thesis utilise different terms, such as the examples provided above to describe students' and teachers' 'knowledge about science.' For the purposes of this thesis, the various terms utilised in these studies will be assumed to be synonymous with 'NOS,' although it is recognised that subtle differences may exist between terms and their subsequent interpretations.

In addition to the difficulty of commonly defining NOS, science educators, philosophers, historians, psychologists and sociologists characterise the various aspects of NOS in different ways. Lists of characteristics of NOS which have been widely accepted and utilised in recent science education documents such as the AAAS (1990, 1993), and NRC (1996) have been developed by Lederman, Abd-El-Khalick, Bell, Schwartz, and Akerson (2001), McComas et al. (1998), and Osborne, Collins, Ratcliffe, Millar, and Duschl (2003). The following summary has been compiled from a consideration of these listings. Nine aspects of NOS are described below, which are representative of an informed or desirable understanding of the various facets of NOS:

1. Scientific knowledge is empirically based and is generally derived from observations of natural phenomena, although these observations are always influenced by human assumptions and previous knowledge, and are thus theory-laden.
2. Scientific knowledge is subject to change and cannot be considered to be absolute, although it is generally considered to be highly reliable or durable. Thus, scientific theories may change as advances in technology and knowledge provide new evidence which brings into question previous claims. Thus, science has a tentative nature.
3. Science is not characterised by a universal scientific method which may be defined as a strict procedure of observing, testing, hypothesising, and ‘proving’ new knowledge. Thus, the idea of an exact method for doing science is a fallacy.
4. Scientific theories and laws are different types of knowledge and serve different roles in science. Lederman et al. (2001, p. 8) define theories as “inferred explanations for observable phenomena or regularities in those

phenomena." They can only be supported and validated by indirect evidence and as such cannot be directly tested. On the other hand, laws are defined as "statements or descriptions of the relationships among observable phenomena" (p. 8). As such, scientific theories cannot become scientific laws, and scientific laws are not a higher form of scientific knowledge.

5. Scientific knowledge is subjective and theory-laden and recognises that a scientists' background (e.g., training, beliefs, experiences) affects the decisions he or she makes concerning the study, subjects and/or research focus they choose to investigate, how they conduct their research, and how they interpret their observations.
6. Observations and inferences are different concepts in science. Lederman et al. (2001, p. 6) define observations as "descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses)." By comparison, inferences are "statements about phenomena that are not directly accessible to the senses."
7. There is a creative and imaginative aspect to scientific knowledge which recognises that although science is empirical, a major undertaking by scientists is involved in creating hypotheses, inferences and theories to explain phenomena.
8. Scientific knowledge is socially and culturally embedded. As such, the traditions and values of a scientists' culture exert an influence on his/her attitudes and interests. Science is not confined to a narrow, western view of knowledge, as ideas and theories from all cultures contribute to a world view of science.

9. Moral and ethical issues influence the decisions reached by members of the scientific community.

(Lederman et al., 2001; McComas et al., 1998; Osborne et al., 2003)

The following section will provide an overview of the early history of science, which will then be followed by a comprehensive analysis of research pertaining to NOS conducted over the past 50 years.

2.4 Historical overview

2.4.1 Early history and philosophy of science

Prior to the 20th century, scientific thinking was dominated by an inductive view of science which stemmed from the early ideas of Aristotle, which were in turn developed by Francis Bacon in the 17th century. Bacon posited that the method of science was ‘induction’ and this view of science was further developed in the early part of the 20th century by the work of the logical positivists. The logical positivists argued that the purpose of philosophy was to clarify the meanings of statements about phenomena. This inductive view of knowledge highlighted the importance of observation and verifiability.

These views were challenged by the work of Karl Popper who argued that scientific ‘truth’ cannot be arrived at via a process of induction. He expressed a hypothetico-deductive view of science which dismissed the notion of verification, and instead stated that science advances by means of proposing and testing of hypotheses. The observations derived from this testing are then compared with the hypothesis, and if conflicting evidence is present, the hypothesis is falsified. This naïve falsificationist approach views scientific progress as the gradual replacement of older hypotheses with more recent ones which take into account a greater number of observations. The role of scientific testing, therefore, is the falsification of hypotheses (Popper, 1968).

Imre Lakatos further developed the falsificationist view of science later in the 20th century by positing that scientific theories are not rejected on the basis of observations which present conflicting evidence. He stated that theories will continue to be considered valid until a convincing alternative theory is proposed which can account for the conflicting information. Thus, the work of logical empiricists such as Popper, Lakatos, and others was centred on justifying scientific claims, and was consistent with an approach in the history of science referred to as 'internalist,' which was dominant early in the 20th century. This approach placed a heavy emphasis on the history of scientific concepts and tended to disregard the relevant contexts where these concepts were developed (Lakatos, 1970).

The 1960s saw a shift in the way scientific knowledge was viewed with the publishing of Thomas Kuhn's 'The Structure of Scientific Revolutions' (1962). He stressed the importance of attending to details from the history of science when considering scientific ideas. Kuhn's work caused a change in the way science was viewed from previous approaches, such as logical empiricism, which were focused on the justification of scientific claims, to a new approach which highlighted the context of discovery. Kuhn introduced the notion of a ‘scientific revolution’, and detailed that this phenomenon occurs through history at various times when aberrant data and findings start to accumulate in a field of science. Over time, these discrepant findings cannot be accounted for by the prevailing scientific theories, and a crisis occurs. This crisis is resolved when scientists in the field develop an alternative theory to account for the aberrant data and findings, and this theory is accepted by the scientific community. As such, a new scientific tradition begins (Kuhn, 1962).

The notion highlighted by Kuhn that new ideas must be accepted by the scientific community was further developed by sociologists such as Karl Mannheim and Robert Merton. Sociology of science or sociology of scientific knowledge (SSK) emerged as a field of knowledge shortly thereafter, and became a precursor for relativist views of knowledge during the 1970s, which emphasised the social nature of scientific knowledge (Driver et al., 1996). A change in emphasis began to occur later in the 1980s, as cultural aspects of science began to receive attention. These contemporary perspectives dominate current literature in the scientific community.

2.4.2 20th century history of NOS

Comprehensive reviews of the field of research on NOS in science education have been conducted by Lederman (1992) and more recently by Abd-El-Khalick and Lederman (2000a). In the first part of the 20th century NOS understandings were closely linked with an understanding of “The Scientific Method.” During the 1960s the field of NOS was more closely focused on science process skills and enquiry. A change in emphasis began to occur in the 1970s as various scholars began to describe scientific knowledge as empirical, tentative, and unique, amongst other characteristics. These changes continued into the 1980s with characteristics such as human creativity in science, theory-laden observations, and the social and cultural nature of scientific knowledge being utilised to describe important aspects of NOS.

As reported in the previous section, various terms can be utilised to describe students' and teachers' understandings of NOS (for example, epistemological views of science, nature of scientific knowledge, etc.). In a similar vein, students' and teachers' views of NOS can be categorised in various ways. Terms commonly utilised in the literature to characterise participants' views of NOS include inadequate/adequate, naïve/informed, limited/enhanced, undesirable/desirable, underdeveloped/developed, and traditional/contemporary, amongst others. In most studies reviewed in this thesis, the term on the left-hand side of the slash represents a view of NOS considered to be in need of development or representative of a less desirable view, and the term on the right-hand side of the slash represents a view of NOS considered to be positively developed, or representation of an desirable level of understanding. It is important to note that subtle differences in meaning exist between the categories identified. For the purposes of this review, the terms used to categorise NOS views will be reported as they were described in the original study. This study will adopt a 'naïve/informed' categorisation to report changes in participants' NOS views (refer to Section 5.9.1.1 for more details).

In addition, this study will adopt the term ‘view’ to describe participants’ understandings of various NOS aspects and characteristics. Other studies utilise terms such as beliefs, ideas, and conceptions to describe these understandings. For the purposes of this review, the terms used to describe NOS understandings will be reported as they were used in the original study, although it is recognised that subtle differences in meaning can be attributed to these terms, in particular the use of the term ‘belief.’

Lederman’s (1992) extensive review of studies relating to NOS over the past 50 years grouped research efforts into four broad areas of scholarship: (a) assessment of students’ conceptions of NOS; (b) development, use, and assessment of curricula designed to ‘improve’ students’ conceptions of NOS; (c) assessment of, and attempts to improve teachers’ conceptions of NOS; and (d) identification of the relationship among teachers’ conceptions, classroom practice, and students’ conceptions.

Studies which were conducted to assess students’ views of NOS began in the 1950s as a result of science educators’ interest in promoting adequate conceptions of NOS (e.g., Aikenhead, 1972, 1973; Bady, 1979; Broadhurst, 1970; Klopfer & Cooley, 1961; Korth, 1969; Mackay, 1971; Mead & Metraux, 1957; Miller, 1963; Rubba, 1977; Rubba & Andersen, 1978; Wilson, 1954). The results of many of these early studies indicated that students held naïve conceptions of NOS. Importantly, Lederman (1992) noted that consistent results were obtained in these studies despite a variety of assessment instruments being utilised to assess participants’ views.

As a result of these findings, many researchers postulated that students did not possess adequate understandings of NOS and recommended that the curriculum be modified to meet this need. Thus, during this second line of research, researchers and educators began to design curricula and interventions with a primary emphasis on improving students' understandings of NOS. Studies which lent support for curriculum development having a positive effect on students' NOS views included those conducted by Klopfer and Cooley (1963), Gennaro (1964), Crumb (1965), Sorensen (1966), Yager and Wick (1966), and Aikenhead (1979). Studies which did not lend support for curriculum development having a positive effect on students' NOS views included those conducted by Trent (1965), Troxel (1968), Jungwirth (1970), Tamir (1972), and Durkee (1974).

Many of the earlier studies conducted in this area failed to acknowledge the important role the classroom teacher played in these interventions. These studies assumed that the teachers' conceptions of NOS had no effect on the design or the implementation of the curriculum. Numerous later studies in this area reported findings that were inconsistent when conducted with different teachers. Thus, the important role of the teacher in the classroom was highlighted by these researchers, with studies such as those conducted by Merill and Butts (1969), and Ramsey and Howe (1969) supporting the notion that teachers' views and attitudes have some influence on student learning.

Thus, research efforts changed their focus towards assessing and improving teachers' views of NOS. It is important to note that the categorisation of 'teachers' is taken to include preservice and inservice teachers. Early studies which were conducted to assess teachers' conceptions of NOS include Anderson (1950), Behnke (1961), Miller (1963), Schmidt (1967), Carey and Strauss (1968, 1970), and Kimball (1968). General findings which emerged from this research indicated that teachers expressed inadequate views of NOS.

Researchers then began to focus their attention on improving teachers' views of NOS. Abd-El-Khalick and Lederman (2000a) provide an extensive review of attempts at improving teachers' views of NOS. Early studies which sought to improve teachers' views of NOS include Gruber (1960, 1963), Welch and Walberg (1968), Kimball (1968), Carey and Strauss (1968, 1969, 1970), Lavach (1969), Jones (1969), Olstad (1969), Trembath (1972), Wood (1972), Billeh and Hasan (1975), Barufaldi et al (1977), Spears and Zollman (1977), and Riley (1979). Results from these studies indicated that, in general, teachers' views of NOS were not substantially enhanced or improved as a result of the various interventions researchers implemented in these studies. Other results drawn from many of these studies indicated that teachers' views of NOS were independent of their science content knowledge, academic level, teaching level, teaching experience, professional development, subject specialisation, gender, cognitive skills, and other personal characteristics.

More recent studies which were undertaken in an attempt to assess or improve teachers' views of NOS include Ogunniyi (1983), Haukoos and Penick (1983, 1985), Akindehin (1988), Scharmann (1988a, 1988b, 1990), Scharmann and Harris (1992), Shapiro (1996), Bloom (1989), Koulaidis and Ogborn (1989), Cobern (1989), Aguirre, Haggerty and Linder (1990), King (1991), Pomeroy (1993), and Abd-El-Khalick and BouJaoude (1997). Results obtained from these studies indicate that, in general, teachers continue to possess naïve or fragmented views of NOS, and attempts at improving these views have met with little success.

Thus, in general terms, early and more recent research on teachers' conceptions of NOS indicates that teachers generally do not possess desirable understandings of NOS and that attempts to improve their views have been limited in their success, irrespective of individual teachers' academic and personal attributes and aptitudes. A change in research focus occurred as researchers recognised that previous studies had been undertaken with the underlying assumption that teachers' views of NOS were able to be directly conveyed to their students as a result of their practices in the classroom. This assumption failed to consider the possible influence of other variables, such as curriculum constraints and teaching experience on the classroom environment. These insights changed the research focus to one which sought to examine the relationship between teachers' views of NOS and their classroom behaviour and practices.

Studies have been undertaken which support the notion that teachers' views of NOS influence their classroom practice (e.g., Brickhouse, 1989, 1990; Gallagher, 1991; Tobin & McRobbie, 1997), yet others have failed to find an influence (e.g., Abd-El-Khalick et al., 1998; Duschl & Wright, 1989; Lederman, 1999; Lederman & Zeidler, 1987). More significantly, research findings in this area have found that the relationship between teachers' views of NOS and their classroom behaviour and practices are highly complex. Abd-El-Khalick and Lederman (2000a) provide a concise summary of many of the variables which have been shown to influence the translation of teachers' views into their classroom practice. These variables include: (a) pressure to cover content (Abd-El-Khalick et al., 1998; Duschl & Wright, 1989; Hodson, 1993), (b) classroom management and organisational principles (Hodson, 1993; Lantz & Kass, 1987, Lederman, 1995), (c) concerns for student abilities and motivation (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Lederman, 1999), (d) institutional constraints (Brickhouse & Bodner, 1992), (e) teaching experience (Brickhouse & Bodner, 1992; Lederman, 1999), (f) discomfort with understandings of NOS (Abd-El-Khalick et al., 1998), and (g) lack of resources and experiences for assessing understandings of NOS (Abd-El-Khalick et al., 1998).

In conclusion, the notion that students will develop informed views of NOS as a direct result of their teacher possessing informed views of NOS is a naïve one that has not been empirically supported. The following section will detail recent trends in the field of NOS which have been the focus of many studies over the past five to ten years.

2.5 Recent research in NOS

An analysis of recent research trends in the field of NOS has highlighted two broad areas of interest, both of which are concerned with instructional approaches which aim to develop participants' views of NOS. This section will review studies which are concerned with these instructional approaches, namely (a) explicit and implicit instructional approaches, and (b) contextualised and decontextualised instructional approaches. This section will review studies conducted in these areas across primary school students, middle school students, high school students, university science and non-science students, scientists, preservice teachers, and inservice teachers.

2.5.1 Implicit instructional approaches

Implicit approaches to teaching NOS are underpinned by the view that an understanding of NOS will result from engaging learners in inquiry-based activities, without the addition of deliberately-focused (explicit) NOS instruction. Implicit approaches to NOS instruction assume that "…an understanding of NOS is a learning outcome that can be facilitated through process skill instruction, science content coursework, and 'doing' science" (Abd-El-Khalick & Lederman, 2000a, p. 673). A review of studies conducted in this area will show that an implicit approach to NOS instruction has been largely ineffective in promoting desirable understandings of NOS.

Studies which have utilised an implicit approach to NOS instruction include Barufaldi et al. (1977), Haukoos and Penick (1983, 1985), Linn and Songer (1993), Meichtry (1992), Moss, Abrams, and Robb (2001), Palmquist and Finley (1997), Riley (1979), Sandoval and Morrison (2003), Scharmann (1990), Scharmann and Harris (1992), Schwartz, Lederman, and Thompson (2001), Smith et al. (2000), Spears and Zollman (1977), Trembath (1972), and Vhurumuku, Holtman, Mikalsen, and Kolsto (2006). Many of these studies, particularly the early ones (all of which were quantitative in nature), reported that participants made improvements in their views of NOS as a result of implicit NOS instruction. A detailed analysis of the findings from these early studies was carried out by Abd-El-Khalick and Lederman (2000a), who highlighted numerous discrepancies in the reporting and interpretation of the results in many of these studies.

For example, Barufaldi et al. (1977) reported an improvement in preservice elementary teachers' conceptions of NOS as a result of taking part in a science methods course, but a careful inspection of the study's results indicated that although there was a statistically significant difference in pre- and post-test scores for the treatment group, the gains achieved were very small (in the range of 3.5 - 6.0 percentage points). The authors also failed to report pre-test scores or mean gain scores for either the control or treatment groups. Similar findings were highlighted when a study of preservice elementary teachers by Trembath (1972) was examined. He also reported improvements in participants' NOS views, and although the difference in pre- and post-test scores was statistically significant, gains achieved were marginal. Methodological concerns were also noted in studies conducted by Haukoos and Penick (1983, 1985), Scharmann (1990), Spears and Zollman (1977), and Scharmann and Harris (1992).

An analysis of the problems inherent in many of the data collection instruments utilised in these studies is presented in further detail in Section 2.7. Later studies, which have been predominantly guided by a qualitative approach to data collection and analysis, appear to have ameliorated many of the methodological issues present in earlier studies, such as the examples reported above. Thus, a post-hoc analysis of the findings from the majority of these early studies found that implementing an implicit instructional approach did not lead to substantial improvements in participants' NOS views. Three recent studies have also reported similar findings.

Moss et al. (2001) examined year 11-12 students' views of NOS over an academic year during a project-based environmental science class, which emphasised a hands-on instructional approach. Students' views of NOS were analysed using a model of NOS developed by the authors consisting of eight tenets that addressed the nature of scientific knowledge and the nature of the scientific enterprise. Findings indicated that although participants held fully formed conceptions of approximately half of the NOS premises in the model, their views remained largely unaltered over the course of the academic year. This study was guided by the assumption that engaging students in project-based activities would allow them to develop a more informed understanding of NOS. Thus, implicit approaches to NOS instruction were largely ineffective in improving or developing participants' NOS conceptions in this study.

Similar findings were evident in a recent study reported by Schwartz et al. (2001), who examined an experienced teachers' classroom practices and her grade nine students' views of NOS and scientific inquiry (SI). Using an implicit NOS instructional approach, the teacher conducted six classroom investigations over a nine week period. Data included classroom observations, post-lesson discussions, classroom documents, student responses to three questions about NOS posed at the commencement of the study, student responses to an open-ended NOS questionnaire, and follow up interviews. Results indicated that students generally held naïve views of NOS at the commencement and conclusion of the study, and the researchers recommended that an explicit approach to NOS instruction is necessary during science instruction.

Sandoval and Morrison (2003) investigated middle school students’ responses to a nature of science interview prior to and after a four-week, inquiry-based unit on evolution and natural selection. Students generally held naïve views of NOS at the beginning of the study. At the conclusion of the study there was no substantial change in students’ views which remained naïve. Students’ responses across the nature of science interview were fragmented and unstable, and the authors suggest that these results do not lend support for the notion that students hold consistent and stable NOS frameworks. They suggest that engaging students in inquiry practices has little direct influence on their formal views of NOS, and propose that epistemological ideas need to be attended to explicitly.

Conversely, two recent studies lent support for the implementation of an implicit approach. Palmquist and Finley (1997) investigated 15 preservice secondary science teachers’ views of NOS during a science teaching methods sequence. Data sources included open-ended surveys and follow up interviews, and classroom observations, and results indicated that many participants’ views of NOS changed from traditional (empirical or positivist) to contemporary at the conclusion of the study. The authors concluded that teaching strategies such as cooperative learning and conceptual change provide an avenue for improving participants’ views of NOS, without direct instruction about NOS. It is important to note that the findings of this study have been scrutinised by some science educators with regard to the meaning and interpretation of terms such as 'direct teaching.'

Another study that reported positive results with an implicit approach to NOS instruction was reported by Smith et al. (2000). They studied two groups of grade six students over a six-year period, from the commencement of their elementary schooling through to grade 6. They found that students in the 'constructivist group' developed markedly more informed views of NOS than students in the 'comparison group.' This longitudinal study was unique in that the students were instructed by the same teacher for the entire six year period, and the teacher planned for, and implemented authentic inquiry practices such as the investigation of pertinent, complex scientific questions; engagement in metacognitive discourse, and self-regulated learning. As such the students in the constructivist group were exposed to a unique science learning experience which was sustained over a long period of time. Implications from this study suggest that implicit, inquiry-oriented instruction can lead to informed views of NOS, if it is carried out and sustained over many years.

A recent study conducted by Vhurumuku et al. (2006) examined 72 Zimbabwean high school chemistry students' images of NOS as they engaged in school laboratory work. No explicit NOS instruction was provided to the students. Data were obtained through responses to open-ended questionnaires and interviews, and results indicated that students developed some understandings of the NOS as a result of engaging in laboratory work. The authors note that some of the images of science displayed by the students indicate that the role of laboratory activities in this setting (which were predominantly verificationist and confirmatory in nature) may lead to the implicit transferring of inaccurate NOS understandings. The authors suggest that the science education curriculum in Zimbabwe needs to change its emphasis from implicit NOS instructional approaches to explicit approaches. Thus, although this study lends support for the notion that implicit transference of NOS understandings is possible, it also highlights the notion that this instructional approach can lead to the development of undesirable NOS understandings.

Based on the research findings presented above, a general conclusion could be proposed that implicit approaches to NOS instruction do not appear to be effective in improving participants' views of NOS. The majority of studies reported above found that an implicit approach to NOS instruction did not result in improvements in participants' views of NOS, and recommended the adoption of an explicit NOS instructional approach. An analysis of explicit approaches will now be detailed.

2.5.2 Explicit instructional approaches

An explicit NOS instructional approach deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion and questioning. Recent studies conducted in this area have emphasised the importance of utilising an explicit, reflective approach to NOS instruction, which draws on the above definition of 'explicit' and adds a reflective component which is concerned with "the application of these tactics in the context of activities, investigations, and historical examples used in daily science instruction" (Schwartz & Lederman, 2002, p. 207). This type of instructional approach is based on the assumption that

NOS instruction should be planned for, and implemented in the science classroom as a central component of learning, not as an auxiliary learning outcome. Many of the studies reviewed in this section annotate the term ‘explicit/reflective’ to ‘explicit’ in the reporting of their studies, with subtle differences in interpretation noted.

Importantly, an explicit, reflective approach to NOS instruction is not the same as directly teaching NOS understandings to students in a transmissive, repetitive fashion. Many explicit, reflective teaching approaches also incorporate inquiry-based science activities, and some include examples from the history of science (HOS). Khishfe and Abd-El-Khalick (2002) provide a succinct definition of an explicit, reflective approach which they describe as an instructional approach which “emphasises student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects” (p. 555).

Numerous studies have been conducted that have utilised an explicit approach to NOS instruction (e.g., Abd-El-Khalick, 2000; Abd-El-Khalick & Lederman, 2000b; Abd-El-Khalick et al., 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson et al., 2006; Akindehin, 1988; Billeh & Hasan, 1975; Bright & Yore, 2002; Carey & Strauss, 1968, 1970; Clough & Olson, 2001; Gess-Newsome, 2002; Hanuscin et al., 2006; Irwin, 2000; Johnston & Southerland, 2002; Jones, 1969; Khishfe & Abd-El-Khalick, 2002; Kurdziel, 2002; Larson, 2000; Lavach, 1969; Lederman, 1999; Lederman et al., 2006; Meyling, 1997; Ogunniyi, 1983; Olstad, 1969; Shapiro, 1996; Southerland & Gess-Newsome, 1999; Wolfer et al., 2001). An important finding from an examination of this body of research is that the majority of these studies reported improvements in participants' views of NOS as a result of explicit NOS intervention. This section will review some of these studies in detail, and will provide evidence to indicate that explicit NOS instructional approaches provide an effective avenue for promoting improved understandings of NOS.

An examination of many early studies that have utilised explicit instructional approaches to NOS have uncovered many methodological issues, some of which were discussed in the previous section. Many of the early studies conducted in the field of NOS prior to the 1990s utilised quantitative methods, and many of the interpretations and conclusions which have been reported by the researchers who carried out the studies raise concerns. For example, Billeh and Hasan's (1975) investigation of inservice science teachers' views of NOS during a science methods course reported improvements in participants' views of NOS, and although there was a statistically significant gain in test scores for the experimental group, the gain was modest. Ogunniyi (1983) and Olstad (1969) reported similar findings with only small gains in test scores.

An early study conducted by Lavach (1969) that examined inservice science teachers' conceptions of NOS reported a statistically significant gain in the experimental group's scores at the conclusion of the study, but importantly failed to pre-test the control group. A similar methodological issue was evident in Akindehin's (1988) study of preservice secondary science teachers' views of NOS. He reported a statistically significant gain in the experimental group scores, but did not disseminate mean pre- or post -test scores. Thus, the findings from this early body of research should be viewed with caution.

In contrast, three early studies were identified which did not present methodological issues. Carey and Strauss (1968, 1970) examined preservice and inservice secondary science teachers' views of NOS during science methods courses. NOS ideas were introduced into the courses by utilising instruction in the history and philosophy of science during lectures, discussions, and readings. Data analysis indicated that participants in both studies made substantial improvements in their understandings of NOS as a result of the courses. Jones (1969) examined non-science university students' views of NOS during a physical science course and obtained similar results.

Subsequent studies conducted during the past ten to fifteen years have generally utilised qualitative research methods which has removed many of the methodological issues present in earlier studies. These studies have utilised inquiry-based science activities, examples from the history of science (HOS), or a combination of both to teach students about NOS. Five studies which have utilised a predominantly inquiry-based, explicit approach will be discussed below.

A year-long case study was conducted by Larson (2000) who examined a chemistry teacher and his students' views of NOS. An ethnographic methodology which utilised interviews, participant observer field notes, and text analysis was employed during the study. The teacher, who held informed views of NOS explicitly exposed his students to NOS concepts during classroom lectures and discussions. Interviews conducted at the end of the study indicated that the majority of students also held informed views of NOS. The author identified six instructional techniques that were found to aid in the development of informed NOS views: (a) teacher modelling of attitudes and inquiry skills, (b) using anecdotes to aid in understanding scientific concepts, (c) using explicit language, (d) utilising questioning techniques which challenged student thinking, (e) providing a supportive classroom environment, and (f) integrating independent science projects in the classroom.

Meyling (1997) also explored secondary school students' views of NOS in a longitudinal study. Over a two year period, physics students from years 10-13 were interviewed and responded to open-ended and multiple-choice questionnaires about the epistemology of science. An explicit NOS instructional approach was utilised in the classroom and results indicated that the majority of students' views of NOS improved as a result of the course. An additional finding from this research was that instruction in NOS constituted less than 10% of classroom time, thus not compromising the teaching of other important cognitive objectives.

A study conducted with university science students also reported improvements in NOS views. Wolfer et al. (2001) examined two chemistry inquiry laboratories over a university semester to ascertain whether the laboratories influenced science students' views of NOS. Instruction in one laboratory group included a unit which emphasised explicit instruction in NOS, whilst the second laboratory group received no instruction in NOS. Findings from pre- and post-tests, using an open-ended NOS questionnaire (a modified version of the VNOS-C, Abd-El-Khalick et al., 1998), indicated that the students who received explicit instruction in NOS showed greater improvement in their understanding of several aspects of NOS, than those who received no instruction in NOS.

Khishfe and Abd-El-Khalick (2002) also compared explicit and implicit inquiry-oriented instructional approaches in their investigation of 62 elementary school students' views of NOS. Students were allocated to one of two groups, with both groups engaging in the same inquiry-based activities. In addition, the 'explicit' group engaged in reflective activities about relevant aspects of NOS. No explicit references were made about NOS in the implicit group. An open-ended NOS questionnaire and follow up interviews were used to assess students' understandings of the target aspects of NOS at the commencement and conclusion of the 2.5 month intervention. The majority of students in both the explicit and implicit groups held naïve views of the target aspects of NOS at the beginning of the study. At the end of the study, there was no substantial change in the views of NOS of the students in the implicit group. In contrast, there was a substantial improvement in students' views of some of the target NOS aspects in the explicit group.

A recent large-scale, longitudinal study was conducted by Lederman et al. (2006) who reported the results of a five year professional development program entitled Project ICAN (Inquiry, Context, and Nature of Science) designed to improve students' and teachers' understandings of NOS and scientific inquiry, and enhance teachers' NOS instructional approaches. This large scale project implemented an explicit, reflective instructional approach and involved 235 science teachers and 23,500 students. Data sources included open-ended NOS questionnaires (VNOS-D), video-taped lessons, student work samples, and written lesson plans. Results indicated that both teachers and students displayed enhanced understandings of many aspects of NOS at the end of the study. Teachers' pedagogical skills for teaching NOS were also examined and results indicated that these skills were substantially improved as a result of the intervention.

In summary all five of the above studies reported improvements in participants' NOS understandings when explicit NOS instruction was provided in inquiry-oriented courses. Other studies that have utilised examples from history of science (HOS) during explicit NOS instruction have reported mixed findings. Three of these studies will now be considered.

Positive results were reported by Irwin (2000), who conducted an action research study of 50 secondary school students over eight lessons which focussed on the use of the historical perspective in the teaching and learning of science. One group of 14-year old students studied a science unit which included historical material in addition to science content material, whereas the other group of 14-year olds studied a science unit with identical science content, minus the historical material. Results indicated that the students from the historical unit were better able to appreciate the creative role played by past scientists and the tentative nature of scientific knowledge. Another important finding from this study showed that students' understanding of science content was not affected by the introduction of historical material.

Interesting findings were reported by Kurdziel (2002), who investigated 137 college students' views of NOS across three different introductory biology courses over a single semester. All participants were non-science majors and each of the three courses was offered by different departments and incorporated varied teaching strategies and differing approaches to NOS instruction. Two of the courses were categorised as traditional, one of which utilised examples from history of science but did not include discussions of these examples, and the other which utilised examples from HOS, but also discussed relevant aspects of NOS during class sessions. The first of these traditional courses was thus labelled as an implicit NOS teaching approach, and the other traditional course was labelled as an explicit NOS teaching approach. The remaining course was categorised as inquiry-based and required students to take part in original scientific investigations. This course was offered twice, with smaller enrolments than the traditional courses, and was labelled as an explicit NOS teaching approach as it incorporated classroom discussions of various relevant NOS aspects.

Participants' conceptions of NOS were assessed at the commencement and conclusion of the study using an open-ended NOS questionnaire (VNOS-C, Abd-El-Khalick et al., 1998) and follow up interviews, and a quantitative NOS instrument (PASE 8.0, McComas, Cox-Petersen, & Narguizian, 2001). Results indicated that the majority of participants held naïve views of many aspects of NOS at the beginning of the courses. At the conclusion of the courses, results indicated that students' views of many aspects of NOS were largely unchanged in the two traditional courses. There were more substantial improvements in students' views of some aspects of NOS in the inquiry courses. Thus, findings from this study indicated that an explicit approach to teaching NOS which solely incorporated examples from HOS did not result in improvements in participants' views of NOS, whereas inquiry-based explicit approaches to teaching NOS resulted in improvements in participants' views of NOS.

Abd-El-Khalick and Lederman (2000b) explored 166 college students' and 15 preservice secondary science teachers' views of NOS during a 10-week history of science (HOS) course. Using an open-ended NOS questionnaire (adapted from Lederman and O'Malley, 1990, and Abd-El-Khalick et al., 1998) and semi-structured interviews as data sources, results indicated that the majority of participants possessed inadequate conceptions of many aspects of NOS at the study's commencement. Data analysis at the conclusion of the study indicated that participants' views of NOS remained largely unchanged, although the authors noted that the majority of changes evident in participants' NOS views could be directly related to NOS aspects that were given explicit attention in their respective HOS courses.

A general conclusion from an examination of the above three studies indicates that inquiry-oriented, explicit instructional approaches which incorporate examples from HOS to teach NOS appear to be more successful than explicit instructional approaches that solely utilise examples from HOS to teach NOS.

Some recent studies (e.g., Abell, Martini, & George, 2001; Akerson & Abd-El-Khalick, 2002; Ryder & Leach, 1999; Ryder et al., 1999; Wang, 2001) have highlighted difficulties that could be experienced when implementing an explicit NOS instructional approach. Akerson and Abd-El-Khalick (2002) examined the classroom practices of an experienced elementary teacher over a school year, who sought to emphasise aspects of NOS in her grade 4 classroom. The teacher held informed conceptions of NOS and was motivated to teach aspects of NOS to her students. Data sources included an open-ended NOS questionnaire (modified VNOS-B, Lederman et al., 2001), interviews, videotaped science lessons, and reflective logs. Results indicated that the teacher required guidance from the researchers to explicitly teach NOS aspects to her students, and her students' views of NOS remained naïve and unchanged throughout the study.

Research conducted by Abell et al. (2001) aimed to provide explicit instruction about NOS during a science methods course. Data analysis revealed that the implemented instructional attempts were more aligned with an implicit NOS approach, which highlights the difficulties teachers may experience when attempting to implement an explicit NOS instructional approach in the classroom. Similar findings were reported by Wang (2001) who designed an inservice NOS program to help develop elementary science teachers' understandings of NOS, and to assist them in translating their conceptions into practice. Each of the 10 participants completed an open-ended NOS questionnaire (adapted from Lederman & O'Malley, 1990; Abd-El-Khalick et al., 1998) and follow-up interviews. Other data sources included videotaped science lessons and teaching plans. During the intervention several aspects of NOS were explicitly addressed through utilising examples from HOS and various classroom activities. Results indicated that although many participants possessed informed views of many aspects of NOS at the commencement of the study, they could not explain how they would teach these aspects to their students. At the conclusion of the study, some participants could describe how they could teach aspects of NOS implicitly, but not explicitly. The author noted that many of the participants did not regard the teaching of NOS as an important learning outcome for students.

The above three studies highlight a notable point – the central role of the teacher in providing an explicit NOS instructional approach to their students. Results from these studies indicate that teachers may require support to enable them to implement this mode of instruction competently, and they also need to prioritise the teaching of NOS as an important cognitive outcome for their students. These findings have important implications for science teacher education programs that aim to provide preservice teachers with the necessary skills and knowledge to enable them to teach all aspects of science, including NOS.

In conclusion, an analysis of the findings reported in the previous studies provides evidence of the effectiveness of explicit approaches to NOS instruction to aid in promoting improved understandings of NOS. Specifically, the implementation of explicit instruction in inquiry-oriented courses was found to be more effective than utilising examples solely from HOS in explicit NOS instructional courses. The following section will examine an area of NOS research that has been the focus of many contemporary studies in the field – contextualised NOS instructional approaches.

2.5.3 Contextualised and decontextualised instructional approaches

A contextualised NOS instructional approach relates and integrates relevant aspects of NOS to the science content being taught, whereas a decontextualised NOS instructional approach incorporates generic activities and/or instruction about various NOS aspects that are not directly related or linked to the science content being taught. Studies which have adopted a contextualised or decontextualised instructional approach to teaching NOS may also incorporate explicit NOS instruction.

A contextualised instructional approach is supported by recent developments in the areas of cognition and history of science as it "recognises the sociocultural dimensions of problem solving, and makes it easier for students to connect with their prior experiences. This encourages students to articulate or construct meanings in specific situations" (Koul & Dana, 1997, p. 132).
The importance of 'context' emerged in the NOS literature during the 1990s, with three influential European studies highlighting a possible relationship between students' views of NOS and science context. The first of these studies was conducted by Leach et al. (1997) who examined young people's views of NOS at ages 9, 12 and 16. Diagnostic instruments or probes were designed and utilised to elicit students' views of NOS in multiple scientific contexts. Students were required to complete tasks and detail their actions and responses to various questions within the context of the activity. Seven probes were used in the study and results indicated that students' reasoning and views about NOS displayed a

tendency to be context bound. The authors concluded that students' may draw on different views or aspects of NOS in different science contexts.

Similar findings were reported by Ryder et al. (1999) who investigated 11 final-year university science students' views of NOS during project work over a 5-8 month period. Students' images of science were evaluated through a series of open-ended questions about NOS posed during interviews throughout the study. Many students at the commencement of the study exhibited naïve views of some aspects of NOS. At the conclusion of the study many students exhibited improved views of some aspects of NOS. Other results indicated that students' views of some aspects of NOS were related to the science context being investigated. The authors concluded:

> …students' images of science are constructed informally from a wide range of experiences of science. These images of science will have been assembled without conscious attempt to construct a systematic image of science to be deployed in all contexts. As a result, individual students have a profile of images of science. A student exhibiting a particular image of science in one context may deploy a different image of science in another. The breadth of the profile reflects the number of different images of science available to the student. (Ryder et al., 1999, p. 203)

They also recommended that studies which seek to assess students' views of NOS need to be designed to enable discussions about aspects of NOS within a variety of science content areas, thus allowing students to express their views of NOS in different contexts.

Leach, Millar, Ryder, and Sere (2000) examined 731 European science students' responses to two written diagnostic questions used to assess their views of NOS, as part of a larger study which investigated students' epistemological views in a range of laboratory contexts. Student responses were examined using decontextualised NOS questions to determine whether there was any evidence of students holding consistent NOS views. Secondly, student responses were examined using contextualised NOS questions to determine the type of NOS framework held by students. A comparison was carried out to investigate whether students possessed integrated conceptions of NOS that were applied consistently, regardless of context.

Results indicated that the majority of students drew upon different views of NOS in different contexts. Student responses were inconsistent over the range of survey questions, and the authors proposed that students' views of NOS cannot be predicted from generalised, decontextualised questions about NOS. They also stated that there is no evidence to suggest that students hold coherent NOS frameworks that they can consistently apply over a range of science contexts. The authors question the value of using decontextualised questions to assess students' views of NOS, and recommend the use of a contextualised approach to NOS instruction and assessment.

The results of these three studies provide evidence of a possible relationship between students' and teachers' NOS understandings and context, with results indicating that students may express different views of NOS in different contexts, with the recommendation of incorporating contextualised NOS instruction and assessment in future studies. A number of related empirical studies have been conducted since these results were published that have either implemented or recommended the use of a contextualised NOS instructional approaches to aid in improving participants' views of NOS. Four of these studies will be discussed below.

Clough and Olson (2001) studied six inservice secondary science teachers' classroom practice to determine the quantity and quality of NOS instruction implemented over a semester. Prior to classroom teaching, participants took part in a course created by the first author which focussed on the development of decontextualised and contextualised strategies for explicitly teaching NOS. Data sources included a NOS questionnaire (VOSTS), a self-efficacy questionnaire (modified STEBI), various writing tasks related to NOS, and a unit of work to implement in the classroom which incorporated both contextualised and decontextualised NOS instructional strategies. Analysis of these data sources at the end of the course indicated that participants held informed views of NOS and felt they could positively convey these notions to their students.

Teachers were observed and interviewed three times during the classroom teaching phase of the study, and their students completed a questionnaire about the quantity and quality of NOS instruction in the classroom. In addition, structured interviews were conducted with each participant at the conclusion of the study. Results indicated that the majority of teachers implemented NOS instruction while teaching science content, whilst the remaining teachers implemented NOS instruction decontextually. The authors concluded that "most teachers experiencing a NOS course emphasising practical decontextualised and contextualised NOS instruction will implement NOS at high levels" (Clough & Olson, 2001, p. 10). This study also lends support for the notion that effective NOS instruction is possible with only minor changes to the existing curricula.

Another recent study conducted by Johnston and Southerland (2002) investigated the development of inservice teachers' views of NOS over a one-semester graduate course on NOS. The course was designed with an emphasis on learning ideas about NOS via explicit instruction, context-specific examples, and reflective activities. Data were collected via NOS questionnaires (administered at the commencement and conclusion of the study, Lederman et al., 2001), classroom activities, and reflective papers. Analysis of data sources indicated that teachers' views of NOS were more sophisticated at the end of the course, thus this study supports explicit, context-specific instruction as a means of enhancing NOS views.

Schwartz and Lederman (2002) studied two secondary science teachers' classroom practices during preservice teaching experience and their first year of inservice teaching. During the course of the study, researchers stressed the importance of addressing NOS instruction in an explicit, reflective manner with the participants. Both participants completed an open-ended NOS questionnaire (VNOS-C, Lederman et al., 2001) three times during the study. Semi-structured follow up interviews were conducted on two occasions after the questionnaires to validate the teachers' responses. Other data sources included lesson plans, mini-teaching assignments, resource cards, post-lesson conferences, and final interviews. Data analysis indicated that the interaction between participants' NOS understandings and content influenced their ability to learn and teach NOS effectively. Viewing NOS as an integral component of science content enabled NOS instruction to be included within science lessons. The teacher with fragmented conceptions of NOS was unable to translate her teaching of NOS to other science contexts.

Other studies have highlighted the limitations of learning about NOS decontextually. A study conducted by Brickhouse et al. (2000) examined how undergraduate students developed their conceptions of NOS over a single semester astronomy course. Data collected included student work samples, interview transcripts, and researcher field notes. Results indicated that students experienced problems when talking and writing about scientific theories in general, but did not experience these same difficulties when they were working with specific theories. Thus, the authors suggest that it is advantageous to learn about NOS in a context where students can relate their understandings to particular theories or phenomena.

Only one recent study was identified in the literature which did not support the favouring of a contextualised NOS instructional approach over a decontextualised NOS instructional approach. Khishfe and Lederman (2006) examined 42 grade nine students' views of NOS during a six week environmental science unit on global warming. NOS was explicitly taught during the unit, with students assigned to one of two groups. The 'integrated' group experienced contextualised NOS instruction, and the 'non-integrated' group experienced decontextualised NOS instruction. Data were collected utilising an open-ended NOS questionnaire and follow up interviews at the commencement and conclusion of the intervention. Results indicated that the majority of students exhibited naïve views of the target NOS aspects at the commencement of the study.

At the conclusion of the study, students' views of the target NOS aspects improved in both groups, although there was a marginally greater improvement exhibited in the informed views of the 'integrated' group, which was countered by a greater improvement in the 'non-integrated' group participants' transitional views of NOS. The authors conclude that the results support the use of an explicit NOS instructional approach, but that the context of instruction was insignificant as both the 'integrated' and 'non-integrated' approaches led to improvements in participants' views of NOS. The authors noted that the controversial nature of the science topic being examined may be an important factor in the effectiveness of the approach, and proposed that future studies investigate this factor.

In conclusion, an analysis of the findings reported in the majority of the above studies provides some evidence of the effectiveness of a contextualised approach to NOS instruction to aid in promoting improved understandings of NOS. As this is an emerging area of research in NOS, further empirical studies are necessary to provide evidence to strengthen this claim.

The following section will review studies which have been conducted with preservice primary teachers in the field of NOS. As stated earlier, the teacher plays a pivotal role in providing NOS instruction to his or her students. Teachers need to learn how to effectively implement NOS instruction in the classroom, and they also need to prioritise learning about NOS in their planning. An ideal environment for this learning to take place is within science teacher education programs. As such, preservice primary teachers were selected as the participants for this study.

2.6 Preservice primary teachers

McComas et al. (1998, p. 15) stress that “teachers represent the most important variable in the classroom learning equation,” and note that NOS interventions utilised in the classroom may be ineffective if they are not aligned with the philosophical beliefs of teachers. As research continues to show that teachers generally express naïve understandings of NOS, developing an informed understanding of NOS must continue to be a crucial goal of NOS research approaches. Science teacher education programs provide an optimal environment for developing the behaviours, practices, and activities necessary for developing an understanding of the nature of scientific activity, and the ability to implement these practices within the classroom. This view is supported by science educators such as Lederman (1992), and Clough (1997).

The terms ‘primary’ and ‘elementary’ are used interchangeably in this thesis. Although it is recognised that subtle differences exist between the terms (for example, ‘elementary’ generally refers to grades K-6 in the USA; ‘primary’ refers to grades P-7 in Queensland, Australia), there is enough similarity between the interpretations to render them interchangeable. For the purposes of this review, the use of the terms ‘primary’ and ‘elementary’ will be reported as they were described in the original study.

This section will firstly outline the various approaches used by researchers to incorporate NOS instruction in science teacher education programs, with a particular emphasis on preservice primary teacher education. Secondly, it will provide a historical overview of previous studies conducted with preservice primary teachers, and examine recent findings and recommendations in this area.

2.6.1 NOS approaches in science teacher education programs

Four main avenues to incorporating NOS have been commonly utilised in science teacher education programs. McComas et al. (1998, pp. 30-32) provide a summary of these approaches:

1. NOS in science methods[1] courses - this approach incorporates the content and pedagogical strategies of NOS within a science methods course,
2. NOS in science content courses - this approach embeds relevant NOS aspects within the teaching of scientific content,
3. Teachers as Scientists - this approach allows participants to have some authentic experience doing science themselves which in turn allows them to talk with some authority about how the science is actually done, and
4. Formal courses in NOS - this approach allows participants to learn about NOS during a course of study specifically focussed on teaching aspects of NOS.

Previous studies conducted in the area of NOS have utilised these various approaches to incorporating NOS in science education programs. Each of these approaches has its own relative merits and drawbacks. For example, although the ‘teachers as scientists’ approach allows its participants to take part in authentic

[1] The phrase ‘science methods course’ is commonly used in the US and is synonymous with the phrase ‘science curriculum course’ in Australia. This review will adopt the phrase ‘science methods course’ and use it throughout this thesis.

scientific practice, this approach often assumes that implicitly exposing participants to scientific inquiry will result in the development of informed understandings of NOS.

A review of NOS literature over the past 50 years has shown that many studies that aimed to improve science teachers' views of NOS were conducted by incorporating NOS instruction in science methods courses. The rationale behind this approach is that "NOS content is discussed in an environment where the curriculum and pedagogical connections can be immediately discussed" (McComas et al., 1998, p. 30). Recently, science educators have begun to question whether science methods courses provide the optimal environment for facilitating the learning of NOS concepts for the following reasons.

First, due to the vast number of topics that are required to be covered in most science methods courses, the topic of NOS often does not receive adequate or satisfactory treatment due to time and content restraints. Secondly, Lanier and Little (1986) have noted that "preservice and novice teachers consistently demand one-to-one correspondence between the content of education courses and anticipated actual teaching content/settings" (cited in Akerson et al., 2000, p. 297). Thus, researchers such as Schwartz and Lederman (2002) are proposing that science content courses may provide a more appropriate environment for educating preservice teachers about NOS as they would better enable teachers to translate their NOS understandings into relevant classroom behaviours and practices.

McComas et al. (1998) have proposed that learning about NOS in science content courses allows participants to experience contextualised NOS instruction. In addition, researchers such as Clough and Olson (2001), and Smith and Scharmann (1999) have postulated that learning about NOS aspects by detaching them from science content does not allow these aspects to be usefully applied to relevant scientific knowledge. As such, Johnston and Southerland (2002, p. 2) suggest that NOS aspects need to be “given a context within the science content that we are more familiar with teaching and learning.” Thus, incorporating NOS learning in science content courses is proposed as an appropriate route to allow contextualised NOS instruction to take place.

A review of the literature revealed a handful of studies that have sought to develop participants’ NOS views during science content courses. A recent study was conducted by Abd-El-Khalick (2000) who investigated 30 preservice elementary teachers’ views of NOS during a science content course which implemented an explicit, reflective, activity-based approach to NOS instruction. At the commencement of the semester-long physics course, participants were introduced to six aspects of NOS through a series of generic activities, and were urged to consider these aspects during their experiences in the course. An open-ended NOS questionnaire (Abd-El-Khalick et al., 1998) and follow up interviews were utilised to ascertain participants’ views of NOS at the commencement and conclusion of the study.

Results indicated that participants held naïve views of several aspects of NOS at the commencement of the study. At the conclusion of the study, many participants exhibited several improvements in their views of NOS, however some participants adopted a naïve relativist view of NOS, instead of an informed relativist view of NOS. The study also found that participants were unable to transfer the NOS understandings they acquired in the context of the science content learnt in the course, to unfamiliar science content.

Hanuscin et al. (2006) investigated nine undergraduate education and science students' views of NOS in a physical science content course designed for preservice elementary teachers. An explicit and reflective approach to NOS instruction was implemented in the course, and all nine students acted as teaching assistants in the course. Data sources included an open-ended NOS questionnaire (VNOS-C) and individual interviews of all participants, as well as classroom observations and document analysis. Eight of the nine participants held largely naïve views of NOS at the beginning of the study. There was no substantial difference between the NOS views expressed by the science or education students. Results indicated that the participants' views of the target aspects of NOS developed over the course of the intervention.

Another recent study was reported by Howe and Rudge (2006), who examined 81 preservice elementary teachers' views of NOS during science content courses (four classes) which were based on historical research on sickle-cell anaemia. The study implemented an explicit, reflective approach to NOS instruction. Using an open-ended NOS questionnaire (modified VNOS) and follow up interviews, results indicated that participants' views of the target aspects of NOS were generally naïve and fragmented at the beginning of the study. Little change was evident in participants' NOS views at the conclusion of the study, but the authors noted that many individual students' views of some of the target aspects of NOS were improved as a result of the intervention.

Thus, the findings from the limited number of studies conducted with preservice primary teachers in science content courses are inconclusive. All of the reviewed studies report some improvements in participants' views of NOS, although the improvements reported in two of the studies were minimal. Thus, although science content courses have been proposed as providing an optimal environment to enable contextualised NOS instruction to occur, more evidence is needed to substantiate this claim.

2.6.2 Overview of NOS studies conducted with preservice primary teachers

NOS studies have been conducted with preservice primary teachers for over 35 years. Early studies were designed with the aim of improving participants' views of NOS. An important early study was carried out by Olstad (1969) who sought to assess preservice elementary teachers' views of NOS during a science methods course. NOS ideas were addressed during lectures and laboratory sessions and results indicated that participants' views of NOS slightly improved over the duration of the course. Notably, Olstad utilised an explicit approach to NOS instruction, whilst three other early studies conducted with preservice elementary teachers implemented NOS instruction implicitly.

Two of these studies, Trembath (1972), and Barufaldi et al. (1977), reported improvements in participants' conceptions of NOS as a result of the interventions, but these findings have been subject to criticism with respect to methodological issues in the reporting and interpretation of results (refer to Section 2.7 for more details). The third study conducted by Riley (1979) also utilised an implicit approach, but found no improvement in participants' NOS views. A study carried out in the early 1980s by Ogunniyi (1983) which integrated history and philosophy of science into a science education course found that preservice elementary teachers' views of NOS improved as a result of the course. Again, these findings are questionable, due to concerns regarding the interpretation of findings.

More recent studies conducted with preservice primary teachers have also sought to assess and/or develop participants' views of NOS. Three recent studies which assessed participants' NOS views all reported similar findings. Abell and Smith (1994) assessed 140 preservice elementary teachers' conceptions of NOS by examining their responses to the question 'What is science?' Results indicated that participants expressed realist and positivist views of science. Similarly, Murcia and Schibeci (1999) examined 73 preservice elementary teachers' views of NOS enrolled in an introductory physical science course, using newspaper science reports as a stimulus to aid participants in expressing their views of NOS. Using open-ended questions to probe their views, results indicated that some of the views expressed by participants were not aligned with contemporary notions of NOS. Mellado (1997, 1998a, 1998b) reported similar results in his investigation of four preservice science teachers' views of NOS and their classroom practice. Using interviews, classroom observations, and document analysis, data analysis indicated that participants held fragmented views of NOS, and that there was no relationship between participants' views of NOS and their classroom practice.

Other researchers have designed interventions aimed at improving or enhancing preservice primary teachers' NOS views. A significant finding that has emerged from recent research in this area is that studies utilising an implicit instructional approach (e.g., Abell et al., 2001) reported no improvements in participants' views of NOS; whereas studies employing an explicit instructional approach (e.g., Abd-El-Khalick, 2000; Akerson et al., 2000; Akerson et al., 2006; Bright & Yore, 2002; Gess-Newsome, 2002; Hanuscin et al., 2006; Howe & Rudge, 2006; Shapiro, 1996) all reported improvements in participants' views of NOS.

Abell et al. (2001) assessed preservice elementary teachers' views of NOS during a science methods course that examined the phases of the moon over a six-week period. Using an action research methodology, data sources included classroom observations, field notes, audio-taped group discussions, student reflective journals, and structured interviews. The study sought to implement an explicit NOS instructional approach. Results indicated that students did not make substantial progress in their understandings of various aspects of NOS, and the authors noted that NOS instruction was often more implicit than explicit during the intervention.

Conversely, Bright and Yore (2002) investigated 50 preservice elementary teachers' views of NOS and associated classroom practice during a science methods course that implemented explicit NOS instruction, and an associated teaching practicum. The study was conducted over a one-year period, and data sources included classroom observations of six participants' lessons; documents from lessons including lesson plans, assignments, and unit plans; and responses to a NOS questionnaire. Results indicated that participants made substantial gains in their views of some aspects of NOS, and that their views of NOS did not appear to influence their classroom practice.

Similar findings were reported by Akerson et al. (2000) who examined 50 preservice elementary teachers' views of some aspects of NOS during a semester-long science methods course which utilised an explicit, reflective, activity-based NOS instructional approach. Using an open-ended NOS questionnaire (Lederman & O'Malley, 1990), and follow up interviews, student reflection papers, and a researcher log; results indicated that the majority of participants expressed naïve views of NOS at the commencement of the study. At the conclusion of the course many participants had made substantial progress in their understanding of aspects of NOS.

These results were also supported by research carried out by Gess-Newsome (2002) who examined 30 elementary preservice teachers' views of NOS during a 10-week science methods course that emphasised explicit, embedded NOS and SI (scientific inquiry) instruction. Journals were utilised as data sources during the intervention and findings indicated that participants' naïve pre-study NOS views changed to more appropriate, contemporary views of NOS at the conclusion of the study.

In a more recent study, Akerson et al. (2006) examined 19 preservice elementary teachers' views of NOS during a one-semester science methods course that implemented explicit, reflective NOS instruction. Data sources included an open-ended NOS questionnaire (VNOS-B) and follow up interviews. Participants exhibited inadequate views of NOS at the commencement of the study, but improvements were evident at the end of the intervention. Participants were interviewed again regarding their views of NOS five months after the intervention, and results indicated that several of the participants' views of NOS reverted back to their pre-instruction views. The authors recommend that interventions designed to improve preservice elementary teachers' views of NOS should utilise metacognitive teaching methods, in addition to explicit and reflective NOS instruction; and to contextualise NOS aspects throughout the course to improve the retention of their NOS ideas.

In summary, research conducted with preservice primary teachers indicates that an explicit approach to NOS instruction would appear to be the most effective way of improving their views of NOS. This finding is consistent with research conducted with other populations of interest such as primary school students, middle school students, high school students, university science and non-science students, scientists, preservice secondary science teachers, and inservice teachers.

2.7 Methodological implications of previous studies

This section will outline some of the methodological implications evident from an examination of previous NOS research. Abd-El-Khalick and Lederman (2000a) highlighted the limitations of the various instruments used to assess participants' views of NOS in their comprehensive review of past NOS studies. They found that the vast majority of early NOS studies used standardised paper- and- pencil instruments to assess participants' NOS views. These types of instruments required participants to offer closed responses to the various items of the instrument.

Abd-El-Khalick and Lederman outline two methodological issues with these types of instruments. The first issue arises from the assumption that respondents will interpret the items contained in an instrument in a manner consistent with the aims of the developer, which was also highlighted by Aikenhead, Ryan, and Desautels (1989). They argue that inconsistencies could ensue as these types of instruments pre-suppose that participants comprehend the instruments' statements or questions in the same way the instrument developers would.

A second issue was highlighted by Lederman (1999) who emphasised that standardised instruments mirror their developers' views of NOS, and imposed a biased philosophical view of NOS on respondents. Consequently, participants' views were often labelled by researchers (for example, as empiricist, falsificationist, etc.), and were also assumed to be coherent and integrated.

Abd-El-Khalick and Lederman (2000a) outlined a further limitation of standardised instruments and stated that their use limits the possibility of making inferences about the importance and value of the gains in NOS understandings exhibited by participants. The majority of the studies reviewed by Abd-El-Khalick and Lederman that used standardised instruments simply reported participants pre- and/or post-test scores or gain scores, with no further elaboration on the meaningfulness of these findings.

The utilisation of open-ended NOS instruments was promoted to avoid the limitations highlighted by the implementation of standardised instruments. Lederman and O'Malley (1990) developed an open-ended questionnaire (VNOS-A) that was designed to allow respondents to explain their conceptions of some target aspects of NOS and the reasoning behind their views. This questionnaire was used in conjunction with individual, semi-structured interviews that were utilised to validate the researcher's interpretations of responses, and to establish face validity of the items. The VNOS-A was later reviewed and modified, and the VNOS-B was developed by Abd-El-Khalick et al. (1998) as a result. Further to these developments, Abd-El-Khalick (1998) modified and expanded the VNOS-B to create the VNOS-C.

Leach et al. (1997), and Leach et al. (2000) have recently identified some methodological implications with respect to NOS instruments or interventions that rely on using decontextualised questions to ascertain participants' views of NOS. As discussed in Section 2.5.3, recent research has indicated that there is little evidence to suggest that participants hold coherent NOS frameworks that they can consistently apply over a range of science contexts. As such, participants may draw on different views of NOS in different contexts. This finding has important methodological implications as the vast majority of NOS studies that have been conducted up until recent times have employed instruments which utilise decontextualised NOS questions, with a couple of notable exceptions (e.g., VNOS-C, VOSTS).

Researchers such as Leach et al. (1997) suggest that instruments need to be designed which utilise contextualised NOS questions or, alternatively, interventions need to be designed which allow participants the opportunity to express their views of NOS across a variety of science contexts. This study will utilise the open-ended VNOS-C to help ameliorate some of these validity issues.

2.8 Summary

The purpose of this review was to situate this study within the broader context of NOS research, and critically analyse recent NOS teaching approaches designed to develop or improve students' and teachers' views of NOS. The theoretical framework that underpins and informs this study is derived from a cultural psychological view of knowledge, which views scientific knowledge as socially constructed.

NOS is commonly defined as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992), and incorporates characteristics such as the empirical, tentative, subjective, creative, and social NOS. Comprehensive reviews of the field of research on NOS in science education have been conducted by Lederman (1992), and more recently by Abd-El-Khalick and Lederman (2000a).

A review of previous NOS research conducted over the past 50 years has highlighted the following general findings: (a) the majority of early and more recent studies which were conducted to assess students' and teachers' views of NOS found that participants held naïve and/or fragmented views of NOS; (b) numerous early and more recent studies which sought to improve students' and teachers' views of NOS reported that participants' views of NOS were not substantially improved as a result of the interventions implemented; and (c) mixed results have been reported from studies which examined whether teachers' views of NOS influenced their classroom practice.

An analysis of recent research trends in the field of NOS has highlighted two broad areas of interest, both of which are concerned with instructional approaches which aim to improve participants' views of NOS - explicit and implicit NOS instructional approaches, and contextualised and decontextualised NOS instructional approaches. Implicit instructional approaches to teaching NOS are underpinned by the view that an understanding of NOS will result from engaging students in inquiry-based activities, without the addition of deliberately-focused (explicit) NOS instruction. A review of early and recent studies that have utilised an implicit instructional approach indicated that participants' views of NOS are not substantially improved as a result of implementing this type of instructional approach.

An explicit NOS instructional approach deliberately focuses learners' attention on various aspects of NOS during classroom instruction, discussion and questioning. This type of instructional approach is based on the assumption that NOS instruction should be planned for, and implemented in the science classroom as a central component of learning, not as an auxiliary learning outcome. An analysis of the findings reported in the reviewed studies provides evidence of the effectiveness of explicit approaches to NOS instruction to aid in promoting improved understandings of NOS. Specifically, the implementation of explicit instruction in inquiry-oriented courses was found to be more effective than utilising examples solely from HOS in explicit NOS instructional courses.

A contextualised NOS instructional approach relates and integrates relevant aspects of NOS to the science content being taught, whereas a decontextualised NOS instructional approach incorporates generic activities and/or instruction about various NOS aspects which are not directly related or linked to the science content being taught. Studies which have adopted a contextualised or decontextualised instructional approach to teaching NOS may also incorporate explicit NOS instruction. An analysis of the findings reported in the majority of the reviewed studies provides some evidence of the effectiveness of a contextualised approach to NOS instruction to aid in promoting improved understandings of NOS. As this is an emerging area of research in NOS, further empirical studies are necessary to provide evidence to strengthen this claim.

Recent research has indicated that the ideal environment for developing an informed understanding of NOS, and to learn the skills, behaviours, and practices necessary for successfully conveying these views of NOS in the classroom, is in science teacher education programs that utilise explicit NOS instructional approaches. Although the vast majority of previous NOS studies have been conducted in science methods courses, some researchers have proposed that a more suitable environment for enabling preservice teachers to learn about NOS and to translate their NOS understandings into instructional practice is within science content courses.

This study will be conducted with preservice primary teachers. NOS studies have been conducted with preservice primary teachers for over 35 years. The findings from the limited number of studies conducted with preservice primary teachers in science content courses are inconclusive. All of the reviewed studies report some improvements in participants' views of NOS, although the improvements reported in some of the studies were minimal. Thus, although science content courses have been proposed as providing an optimal environment to enable contextualised NOS instruction to occur, more evidence is needed to substantiate this claim.

A review of the instruments utilised in previous NOS research has highlighted some methodological implications with many of the instruments used in early studies. A recommendation for the use of open-ended instruments that utilise contextualised NOS questions has emerged from an examination of this literature. This study will utilise the open-ended VNOS-C to help ameliorate some of these methodological issues.

This review has provided evidence to support the adoption of an explicit, contextualised approach to NOS instruction to aid in developing preservice primary teachers' views of NOS. Implementing this instruction within a science content course would appear to provide the optimal environment for allowing these teachers to develop the necessary skills and instructional strategies needed to both develop informed views of NOS, and successfully apply these views of NOS in their classroom practice. The following chapter will provide an overview of studies that have been conducted in the field of argumentation in science education.

CHAPTER 3 – ARGUMENTATION RESEARCH

3.1 Introduction

This chapter will provide an overview of research in the field of argumentation, with a specific focus on studies conducted in science education. The purpose of the review is to situate the study within the broader context of argumentation research, and to critically analyse the various modes and contexts of argumentation instruction. This review will identify explicit argumentation instruction, context of argumentation, and conceptual knowledge as influential factors affecting students' skills and/or quality of argumentation.

The chapter will commence with a brief review of the history and forms of argumentation. The following section will provide an overview of various models of argumentation utilised in science education research, including Toulmin's model of argumentation. A review of previous argumentation research conducted in science education will be discussed, and important trends in the literature will be highlighted. Studies which have incorporated explicit argumentation instruction will be reviewed and analysed, and an examination of the two contexts for argumentation (scientific and socioscientific) will follow. The chapter will conclude with a summary of the major findings from the literature.

3.2 History of argumentation

Argumentation has its roots in ancient times, and is associated with philosophers such as Aristotle and Socrates who were primarily interested in the study of thinking. They posited that the formation of reasoned arguments was central to the act of thinking and their research was guided by a desire to improve or change discourse in society. Reasoning can be subdivided into two main categories, formal reasoning (or logic) and informal reasoning. The study of formal reasoning was the dominant mode of thinking throughout early history and remains an important mode of thinking in current times. It is often associated with academic disciplines such as mathematics and is concerned with producing valid conclusions inductively or deductively from a set of premises. Examples of the various forms of formal reasoning include syllogisms, deductions and fallacies (van Eemeren, Grootendorst, Jackson, & Jacobs, 1996).

Ancient views of logic associated with Aristotle centred on identifying patterns in argumentation which would enable the validity or truth of statements to be established from examining other statements which had previously been shown to be true, thus allowing these patterns to be generalisable to any context. As such, factors such as context have no influence on its form. Therefore, any particular argument was not able to be analysed in terms of its robustness or limitations. From these early Greek beginnings, formal reasoning has continued to analyse argument decontextually. Van Eemeren et al. (1996, p. 7) notes that “the development of modern symbolic logic is a direct response to the concern for representing the inferential structure of seemingly acceptable or unacceptable arguments”.

Informal reasoning also has its roots in ancient times, although it was not the dominant mode of thinking during this period. Its popularity grew during the 20th century as philosophers such as Stephen Toulmin challenged the usefulness of formal reasoning models. The publication of Toulmin's book *The Uses of Argument* (1958) was a pivotal moment in the history of reasoning and argumentation, and as a consequence of its publication many philosophers began to recognise the advantages of utilising informal reasoning as the preferred mode of thinking. Toulmin's informal view of rationality recognised that different discourse contexts varied in their normative organisation (refer to Section 3.4.1 for more details).

The aim of informal reasoning is "to develop norms, criteria and procedures for interpreting, evaluating and constructing argumentation that are faithful to the complexities and uncertainties of everyday argumentation" (van Eemeren et al. 1996, p. 15). This form of reasoning often deals with ill-structured problems that have no clear solution, and which require the application of inductive reasoning to solve. The concept of argumentation which is utilised in the research literature is commonly associated with this type of reasoning and will be discussed in detail in the following section.

3.3 Forms of argumentation

The research literature provides a multitude of definitions and meanings for the term argument, some of which include:

- "The intentional explication of the reasoning of a solution during its development or after it" (Krummheuer, 1995, p. 231),
- "…juxtaposition of two opposing assertions" (Kuhn, 1991, p. 12),

- "…interactive dialogue in which people reason together on a disputed subject" (Walton, 1996, p. 26),
- "an assertion and its accompanying justification" (Toulmin, 1958),
- "the coordination of evidence and theory to support or refute an explanatory conclusion, model, or prediction" (Suppe, 1998).

An examination of this list can often be bewildering for the reader as a simple, singular meaning does not appear to exist for the term. To alleviate this confusion, arguments can be generally categorised into two different, but related forms or types. The first of these forms of argument to be considered are termed rhetorical arguments, and the second, dialectical arguments.

3.3.1 Rhetorical arguments

Historical accounts of rhetoric from the early Greek philosophers, such as Aristotle, viewed rhetoric as "effective persuasion in civil discourse," or alternatively "the study of effective techniques of persuasion" (van Eemeren et al., 1996, p. 7). This view of rhetoric bears little resemblance to contemporary theories. A major change in the way rhetoric was viewed occurred in the 20th century with the publication of *The New Rhetoric* (1969) by Perelman and Olbrechts-Tyteca. The New Rhetoric provided the reader with a wealth of useful argumentation methods and introduced basic principles of contemporary rhetorical theory. Modern views of rhetoric define these types of arguments as "oratorical in nature and are represented by the discursive techniques employed to persuade an audience. In contrast to the other forms of argument where a consideration of the evidence is paramount, they stress knowledge and persuasion" (van Eemeren et al., 1996, p. 11). This view of rhetoric also recognises the situated nature of argumentation.

Driver et al. (2000) discuss the role of rhetoric in science classrooms and note that arguments of this type are utilised by teachers to persuade students of the strength or reasonableness of the scientific idea they are putting forward. They posit that rhetoric has limited application in science classrooms as it is one-sided and does not give students the opportunity to construct their own arguments. They propose that it is imperative for students to practice argumentative skills such as asking questions, justifying claims and proposing alternatives, and assert that an alternative form of argument is required to fulfil this need. This alternative form of argument is termed 'dialectical' and will be discussed in the following section.

3.3.2 Dialectical arguments

Dialectical arguments were described in ancient times as "the art of inquiry through critical discussion" (van Eemeren et al., 1996, p. 9), and consisted of testing a position with the aim of revealing and eliminating contentious points of view. These arguments are closely associated with the Greek philosopher, Socrates. An important class of dialectical argument which originated during this early period was 'argumentum ad verecundiam,' or 'argument from authority.' Argument from authority has been defined as "…a distinctive species of argumentation where one party in dispute tries to exploit the respect of the other party in order for an established authority to make him submit to the first party's argument" (Walton, 1997, p. 34). The term 'argumentum ad verecundiam' has historically been linked to a 17th century publication by Locke, and was considered to be both a reasonable and valid type of argument up until the 18th century, when philosophers began to interpret it as fallacious.

In addition to Locke’s publication, views of knowledge which originated with the development of empirical science challenged the authority of the Church which was dominant prior to the 18th century. Empirical science was based on a positivist view of science which stressed objectivity and experimentation. As such, these views of knowledge were not aligned with the subjective nature of arguments such as ‘argumentum ad verecundiam,’ and this factor also contributed to the view that this type of argument was inherently fallacious (Walton, 1997).

A renewed interest in dialectical arguments arose during the 20th century. Modern views of dialectical arguments recognise that these types of arguments characteristically take place during discussions and involve reasoning with premises that do not necessarily appear to be true. Toulmin’s seminal publication *The Uses of Argument* (1958) regenerated interest in dialectical arguments by introducing the notion of functionalisation. His model focused on the functional relationships between the parts of an argument, instead of simply concentrating on the formal relationships, and as such bears little resemblance to formal models of argumentation (refer to Section 3.4.1 for more details).

More recent developments in dialectical argument theory have been undertaken by Walton (1997), and van Eemeren and Grootendorst(1996), and these theories have collectively been referred to as pragmatic argumentation theories. The purpose of pragmatic arguments is to find a solution to a difference of opinion by exploring the merit of opposing views. The strength of this approach lies in its focus on discussion, as opposed to argument content or form. Pragmatic argumentation theories also focus on the notion of contextualisation as they recognise the “embeddedness of argument within other sorts of interactional business” (van Eemeren et al., 1996, p. 17).

Dialectical arguments have been utilised in early and recent research conducted in the area of science education. These arguments are often referred to as ‘dialogic’ or ‘social’ in this literature base, thus these terms can be considered to be interchangeable. Kuhn (1993) describes dialogic arguments in the following manner:

> In a social (dialogic) argument, at a minimum one must recognise an opposition between two assertions – that, on surface appearance at least, both are not correct. One must then connect supporting and refuting evidence to each of the assertions and, if the argument is to move toward resolution, be able to relate and weigh supporting and refuting evidence in an integrative evaluation of the relative merit of the opposing views. (pp. 322-323)

Driver et al. (2000) have examined the utilisation of dialogic arguments in group settings. They propose that group settings provide an ideal environment to allow the social nature of argumentation to emerge, and conclude that allowing students to practice the skills of argumentation in groups is an “important mechanism for scaffolding the construction of argument by pupils individually” (p. 292).

The following section will review the major models of argumentation that have been utilised in science education (and other fields) over the past 50 years. It will firstly examine Toulmin’s model, the dominant argument framework utilised in previous science education studies.

3.4 Models of argumentation

3.4.1 Toulmin's model

A model of argumentation that has been widely utilised in previous science educational research was developed by Stephen Toulmin. His influential publication, *The Uses of Argument* (1958) questioned previous notions of validity and aimed to describe the process of argumentation in practice. He proposed an informal model of argumentation which enabled individual arguments to be evaluated. His model focused on the functional relationships among elements of an argument, as opposed to the strict forms of argument promoted in formal reasoning or logic. Although Toulmin's model is almost half a century old, it continues to be the most widely utilised argumentation framework in research conducted in science education today.

There are two central features of Toulmin's model. The first of these features is the notion of 'field' of argument. Toulmin (1958) states:

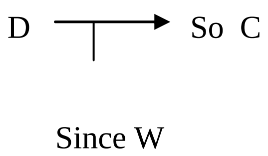
> Two arguments will be said to belong to the same field when the data and conclusions in each of the two arguments are, respectively, of the same logical type: they will be said to come from different fields when the backing or the conclusions in each of the two arguments are not of the same logical type. (p. 14)

He defines 'field-invariant' features as the elements of arguments that are the same irrespective of the field, and 'field-dependent' features are those elements of arguments that vary from field to field.

The second central feature of Toulmin's model is a set of six components which constitute an 'argument.' These six components are described below:

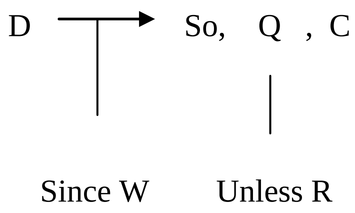
1. Claim (C) - the conclusion whose merit is attempting to be established,
2. Data (D) - the facts which provide the basis for the claim,
3. Warrant/s (W) - propositions that are offered to justify the link between the data and the claim,
4. Backing/s (B) - assumptions or assurances which are agreed upon that provide the grounds for the warrants,
5. Qualifier/s (Q) - specify the particular circumstances or conditions which may restrict or limit the claim, and
6. Rebuttal (R) - the exceptional circumstances or conditions which would disprove the warrant/s and thus defeat the claim.

Following from these six components, Toulmin outlined a pattern for analysing both simple and more complex arguments. Argument form in its simplest sense is represented by the following relationship:

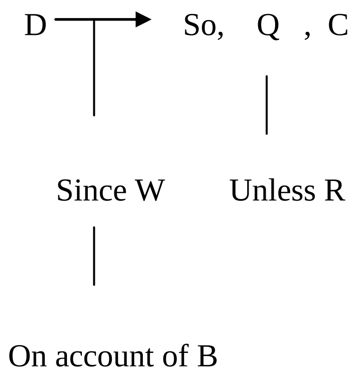


In this pattern, the facts which provide the grounds for the claim (D) are justified by propositions (W) which support the conclusion (C).

In more complex arguments, restrictions on the claim (Q), and conditions which would falsify the claim (R), are specified. Arguments of this form are represented by the following relationship:



In addition to the above conditions, complex arguments may also include information which provides grounds for the warrant (B). This form of is represented below:



Arguments which include a backing for the warrant are termed analytic if the backing implicitly or explicitly contains information communicated in the claim itself. If this information is not communicated in the claim, the argument is termed substantial.

As stated earlier, this model of argumentation is the most widely utilised framework in studies conducted in science education. Although many science educators find this framework to be useful when examining the structure of an argument, others have found the application of this framework is limited and problematic. These concerns will be addressed in the following section.

3.4.2 Limitations of Toulmin's model

Various researchers have suggested that Toulmin's model of argument has limited application for a number of reasons. Duschl et al. (1999) stated that there may be difficulties associated with using this model because of the different ways components of the model, such as data, qualifiers, claims, etc., can be interpreted. This presents validity concerns as "what one choses to monitor and against what criteria shapes the evaluation of the discourse" (p. 7). Van Eemeren et al. (1996) also recognised this point stating that the defining of Toulmin's argumentation components have a tendency to be vague and ambiguous.

Driver et al. (2000) found this model to be problematic as although the model provides a structural assessment of argument form, it fails to assess the correctness or quality of an argument. They posit that subject matter knowledge must be considered in the evaluation of any argument, and that the model fails to consider contextual features. Thus, problems with interpretation may occur, and they highlight the following four points of contention (Driver et al., 2000):

1. The same statement may have a different meaning in a different context, so the context needs to be taken into account in inferring meaning;
2. Parts of arguments such as warrants are often not explicitly stated in speech but are implicit;
3. In the natural flow of conversation points are not necessarily developed sequentially and reference has to be made across extensive sections of the text to identify features of the argument; and
4. Not all points are made through speech as some are made through semiotic gestures, pointing at objects, nodding, etc., especially in science where manipulable materials are used. Moreover, illustrations and graphics are no longer supplementary but a central communicative feature of texts.

(p. 294)

Other researchers have also identified some methodological problems with utilising this model to analyse discourse. Kelly, Druker, and Chen (1998, p. 318) found that “organising student discourse into Toulmin’s argument components required careful attention to the contextualised use of language.” They also noted that the framework did not allow lengthy or complex argument structures to be analysed, and was thus more suited to the analysis of short argument structures.

Various researchers have proposed alternative frameworks to analyse arguments, and some of the models that have be utilised in science education studies will be discussed and evaluated below.

3.4.3 Argumentation frameworks utilised in science education

This section will identify and discuss some of the argumentation frameworks developed and utilised in science education research over the past 20 years. The majority of these frameworks have adapted Toulmin’s basic framework for argumentation and provide an analytical account of argumentation. Some of these frameworks are documented in studies by Alexopoulou and Driver (1997), Eichinger, Anderson, Palinscar, and David (1991), Jimenez-Aleixandre et al. (2000), Kuhn (1993), Kuhn, Shaw, and Felton (1997), Osborne et al. (2004a), Pontecorvo (1987), and Zohar and Nemet (2002). Other argumentation frameworks have been developed that have not been adapted from Toulmin’s model, and these frameworks are reported in studies by Clark and Sampson (2006), Driver et al. (2000), Duschl et al. (1999), Kelly and Takao (2002), and Sandoval and Millwood (2005). This section will firstly outline some of the studies that have adapted Toulmin’s basic framework.

Osborne et al. (2004a) examined the quality of teachers' and students' arguments during a longitudinal study which sought to enhance participants' arguments in both scientific and socioscientific contexts during whole class discussions (refer to Section 3.5.3 for full details of the study). Data sources included audio-taped student conversations and semi-structured teacher interviews. Data analysis incorporated Toulmin's argument framework which was adapted to incorporate some of the epistemic operations developed by Portecorvo (1987). An important feature of Osborne et al.'s framework is the recognition of the central role of rebuttals in rational arguments. The authors state that arguments without rebuttals do not allow the persons engaged in a dialogue to be epistemically challenged, thus not allowing their personal beliefs or views to be questioned.

The framework collapses Toulmin's argument components – data, warrants, and backings, into a single category 'grounds,' in an attempt to alleviate some of the difficulties in differentiating between these argumentation components. The framework developed by Osborne et al. (2004a) defines five levels of quality of argument as follows:

1. Level 1 arguments consist of a simple claim versus a counter claim or a claim versus claim.
2. Level 2 arguments consist of claims with either data, warrants or backings but do not contain any rebuttals.
3. Level 3 arguments consist of a series of claims and counter claims with either data, warrants or backings with the occasional weak rebuttal.

4. Level 4 arguments consist of a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counter claims as well but this is not necessary.
5. Level 5 arguments are extended arguments with more than one rebuttal.

The authors state that their model of argumentation is an improvement on Toulmin's original scheme as it allows the framework to be applied to whole class conversations, thus allowing a detailed assessment of argumentation performance across more than one lesson.

Sadler and Fowler (2006) recently examined 45 high school and college students' application of content knowledge to their arguments about genetic engineering. This mixed-methods study developed a model of argumentation adapted from Toulmin's original framework, that focused on the justification of claims. Similar to Osborne et al. (2004a), this model also collapsed Toulmin's argument components – data, warrants, and backings, into a single category 'grounds.' Unlike Osborne's scheme, which is only applicable to analysing group discourse, this scheme may be used to analyse individual student discourse and performance. Sadler and Fowler's Argumentation Quality Rubric (2006) is defined as follows:

1. Score 0 Description – No justification
2. Score 1 Description – Justification with no grounds
3. Score 2 Description – Justification with simple grounds
4. Score 3 Description – Justification with elaborated grounds

5. Score 4 Description – Justification with elaborated grounds and a counterposition.

(p. 9)

Another argument framework adapted from Toulmin's scheme was developed by Jimenez-Aleixandre et al. (2000) who studied Grade 9 students' abilities to develop and assess arguments during a unit of work on genetics. Data sources included video- and audio-taped student dialogue. Toulmin's framework was utilised to analyse student discourse. In addition, the authors developed their own argumentation framework that enabled them to analyse other aspects of the students' dialogue (e.g., analogies, causal relationships, epistemic operations, etc.) as they found that the use of Toulmin's model alone was not sufficient to allow these types of dialogue exchanges to be interpreted.

Kelly et al. (1998) utilised Toulmin's framework to analyse student discourse during an inquiry-based activity on electricity, but during the data analysis phase of the study some methodological problems arose. The authors experienced difficulties when they attempted to apply Toulmin's model to the longer chains of reasoning present in their participants' written discourse. They also noted that Toulmin's model did not address the different levels of claims which can be present in more complex arguments. Kelly and colleagues later developed a model of argumentation analysis which introduced the important notion of including disciplinary-specific knowledge during the analysis of students' arguments (Kelly & Takao, 2002).

In summary, the argumentation frameworks adapted from Toulmin's original model have added to our knowledge about how students learn to construct arguments and engage in argumentative practices. One shortfall of these structural frameworks is that they do not allow a consideration of how students' subject matter knowledge impacts the arguments they construct, or if this subject matter knowledge changes as a result of engaging in argumentation. Thus, some science educators have proposed that argumentation frameworks need to assess both the structure and the conceptual quality of the arguments students construct (Clark & Sampson, 2006; Driver et al., 2000; Sandoval & Millwood, 2005).

Sandoval (2003) developed an argumentation framework that assessed the quality of arguments presented by high school students studying natural selection. He examined whether students provided data and warrants to support their claims, with results indicating that students often failed to provide sufficient data to support their claims. Sandoval and Millwood (2005) build on the argumentation framework developed in the previous study and examined whether students provide sufficient warrants to support their claims, how they used evidence in their arguments, and how their epistemological views about argumentation influenced their engagement in scientific inquiry.

A recent argumentation model was described by Kelly and Takao (2002) who examined university students' use of evidence in writing by developing an argumentation model based on previous studies by Kelly et al. (1998) and research by Latour (1987) concerning the rhetoric of science. The inclusion of disciplinary-specific knowledge was deemed significant as previous research suggested that content knowledge may influence a participant's ability to engage in scientific argumentation. Kelly and Takao's (2002) model of argument analysis incorporates six epistemic levels. The bottom level consists of the most specific, grounded claims, which leads progressively to the top level which consists of more general, theoretical claims. The model also allows for the incorporation of more than one claim in complex arguments. Thus, students' propositions are able to be arranged into various levels which then allows for an overall analysis of the argument. A semantic network is produced for each argument indicating the connections across epistemic levels, which in turn allows each argument to be assessed and compared to other participants' arguments.

Contemporary educational theory posits that the social environment in which students interact has a significant influence on the dialogue that takes place in a setting. Duschl et al. (1999) recently proposed that an argumentation framework based on presumptive reasoning may be an effective method for incorporating the social aspect of argumentation in science classrooms. They developed a methodological approach for understanding the arguments learners engage in based on Walton's argumentation schemes (1996). Their model of argument analysis, termed 'dialog logic,' integrated the structural, cognitive and social aspects of argumentation by utilising nine of Walton's presumptive reasoning schemes to analyse student discourse.

During a research study which investigated the effectiveness of a science unit designed to develop middle school students' reasoning abilities while evaluating scientific knowledge claims (Duschl et al., 1999), they found that the argument analysis afforded by applying Walton's argumentation scheme identified a greater quantity and quality of argumentation in students' discourse than the argumentation identified when applying Toulmin's analytical framework. The authors suggest that argumentation frameworks such as Walton's presumptive reasoning schemes provide an effective avenue for both assessing and developing learners' argumentation skills and strategies. These findings were also supported by a recent study by Jimenez-Aleixandre and Pereiro-Munoz (2002).

The results reported in the above three studies highlight the complexity of examining learners' argumentative discourse, and provide evidence to suggest that the application of structural frameworks such as Toulmin's model may not enable a full evaluation of argumentative discourse to occur. The importance of assessing both the structure and quality of argumentation is highlighted in these studies. The following section will provide an overview of previous argumentation research conducted in science education.

3.5 Previous studies in science education

3.5.1 Introduction

Argumentation in science education is a relatively new topic in the research literature. Research conducted in this area over the past 20 years will be briefly documented in this section, although it should be noted that this review is neither exhaustive nor fully detailed. An excellent review of previous studies is provided by Driver et al. (2000). The purpose of this review is to provide a general overview of previous research efforts and to highlight important recent trends in the field.

One of the most significant studies in the field of science education which drew attention to the importance of teaching children the skills of argumentation was conducted by Kuhn (1991). She investigated 160 adults and childrens answers to important social questions, and concluded that many of the participants were unable to present valid arguments. These findings have been supported by additional research (e.g., Driver et al., 2000; Jimenez-Alexiandre et al., 2000; Kortland, 1996; Kuhn, 1993; Perkins & Salomon, 1989; Perkins et al., 1991; Zeidler et al., 2002) that indicates that students generally do not formulate sound, evidence-based arguments, nor are they able to evaluate arguments effectively.

Some of the common problems exhibited by students as they engage in argumentation have been documented by Chinn and Brewer (1998), Jimenez-Alexiandre et al. (2000), Zeidler (1997), and Zeidler et al. (2002), and are summarised below:

1. jumping to conclusions based on insufficient data,
2. an inability to evaluate counter-evidence or disconfirming data,
3. an inability to recognise convincing evidence,
4. introducing inferences and reinterpretations and thus bias that are not drawn from the evidence presented,
5. ignoring, rejecting, distorting or excluding data, and
6. ignoring warrants, or only including them when claims are challenged.

A consideration of these problems have led some researchers to suggest that students are not provided with adequate support in the classroom to enable them to develop effective argumentation skills, and propose that explicit instruction in argumentation in the classroom is needed to promote this goal (Driver et al., 2000; Duschl & Osborne, 2002). Research conducted in this area has highlighted that most classrooms are teacher dominated, with students being given little opportunity to learn how to structure arguments, or engage with scientific or social issues (Cross & Price, 1996; Geddis, 1991). In a notable study of high school students' classroom discourse, Newton et al. (1999) found that less than 2% of classroom teaching time was spent engaging students in discussion-based tasks. They also found that teachers did not possess adequate skills to teach argumentation to their students.

Attempts to remedy the dominance of teacher discourse in the classroom have occurred over the past 15 years, and examples of these interventions include studies by Geddis (1991), Herrenkohl and Guerra (1995), Kuhn et al. (1997), Ratcliffe (1996), and Solomon (1992). Thus, a shift from teacher-centred discourse to student-centred discourse is needed to encourage more student-oriented dialogue and argumentation, and teachers need to be provided with adequate training and support to enable them to implement effective argumentative instruction to their students.

Other researchers (Clark & Sampson, 2006; Duschl, 1990) have highlighted the limitations of presenting scientific knowledge as a set of facts to be memorised and regurgitated for assessment. This transmissive approach to teaching science not only provides students with an inaccurate image of the nature of science, but also fails to encourage an exploration of how scientific ideas have developed and changed over time. Thus, students may not appreciate the purpose of discussing and critiquing these ideas, and are less likely to engage in argumentative discourse about how these ideas are developed and validated by the scientific community.

An additional area of research in argumentation has examined the variables that may influence argument skills. Kuhn (1991), Perkins et al. (1991), and Means and Voss (1996) investigated the effect of age on argument skills and found that argumentation skills improved throughout childhood until adolescence, but generally remained stable from adolescence onwards into adulthood. These researchers also examined the influence of previous knowledge on argument skills. Perkins et al. (1991) found that previous knowledge about an issue did not necessarily improve the quality of arguments about the issue, although Means and Voss (1996) concluded that previous knowledge was related to some aspects of argumentation, but not necessarily all of them. Findings from Kuhn's (1991) research indicated that previous knowledge on a topic did not necessarily influence the quality of arguments about that topic, and also that experts in a particular field of knowledge did not exhibit better quality arguments within their field than in another unrelated field.

An underlying assumption in the science education community is that some understanding of scientific content is necessary to allow students to make sense of issues which impact their daily lives (AAAS, 1990, 1993; NRC, 1996). Several studies conducted in the field of argumentation have investigated the relationship between conceptual knowledge and argumentation (e.g., Bell & Linn, 2000;

Driver, 1989; Driver et al., 1994; Eichinger et al, 1991; Fleming, 1986; Hogan, 2002; Jimenez-Aleixandre et al., 1997; Jimenez-Aleixandre & Pereiro-Munoz, 2002; Kortland, 1996; Kuhn, 1991; Lewis & Leach, 2006; Mason, 1996; Means & Voss, 1996; Perkins & Salomon, 1989; Perkins et al., 1991; Pontecorvo, 1987, Sadler & Fowler, 2006; Sadler & Zeidler, 2005; Tytler et al., 2001; Zeidler & Schafer, 1984; Zohar & Nemet, 2002). The results from this large body of research are inconclusive, with many of these studies finding a significant relationship between conceptual knowledge and argumentation, and other studies failing to find a relationship. Many of these studies will be reviewed in the following sections and the implications of conceptual knowledge on argumentation will be discussed. This area of research is the subject of many current empirical studies.

An important area of recent research in the field seeks to investigate the relationship between explicit instruction in argumentation and learners' skills and/or quality of argumentation. Research conducted in this area will be reviewed and discussed in the following section.

3.5.2 Explicit argumentation instruction

Many recent studies have highlighted a possible relationship between learners' skills and/or quality of argumentation, and the inclusion of explicit argumentation instruction in the classroom (e.g., Bell & Linn, 2000; Jimenez-Aleixandre et al., 2000; Osborne et al., 2004a; Yerrick, 2000; Zohar & Nemet, 2002), whereas other studies have failed to find a relationship (e.g., Jimenez-Aleixandre & Pereiro-Munoz, 2002; Patronis, Potari, & Spiliotopoulou, 1999). Explicit instruction in this context refers to the direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function, and application of arguments, and the criteria used to assess the validity of arguments.

This section will also introduce the notion of 'supported' argumentation instruction which is a term used to describe an instructional approach to argumentation that does not explicitly guide learners in understanding the skills of argument, but instead provides prompts and suggestions for constructing arguments or evaluating evidence. Studies that have been conducted with software learning tools or within web-based environments often utilise this type of instructional approach.

This section will review and discuss recent research studies that have examined the influence of different modes of argument instruction on learners' skills and/or quality of argument. A general recommendation which has emerged from recent science education literature (e.g., Kuhn, 1993; Hogan & Maglienti, 2001; Zohar & Nemet, 2002) supports the notion that explicit (or supported) instruction in argumentation is a necessary prerequisite for enabling the development of learners' skills and/or quality of argument. Four studies which lend support for this assertion will be discussed below.

Zohar and Nemet (2002) investigated the knowledge and argumentation skills of nine classes of year 9 biology students engaged in a 12-hour unit on human genetics. Five of the classes comprised the experimental group, and the remaining four classes comprised the control group. The experimental group received explicit instruction in argumentation throughout the unit by two means. First, they took part in a lesson that exclusively dealt with the definition and structure of arguments, the identification of criteria to assess the validity of arguments, and the integration of examples that allowed students to practice applying these principles. Secondly, students participated in a series of 10 moral dilemmas in genetics to enable them to practice their skills of argumentation in a variety of genetics contexts. Throughout the unit, the students were encouraged to ground their decisions on appropriate biological knowledge. The control group did not receive any instruction in argumentation and took part in conventional instruction during the genetics unit. Both groups had learned basic genetics concepts prior to the intervention.

Data analysis of the student discourse utilised an argumentation framework developed from Pontecorvo and Girardet (1993). Results at the end of the intervention indicated that students from the experimental group were able to formulate better quality arguments than students from the control group. Students from the control group also showed no significant development in the quality of their argumentation at the end of the study. It is important to note that approximately 90% of the students from both the experimental and control groups were able to formulate simple arguments at the commencement of the study.

An assessment of students’ conceptual knowledge at the end of the intervention indicated that both groups showed improvement in their genetics knowledge compared with the scores they had obtained prior to the study, with the experimental group showing more significant improvements in their genetics scores. Students in the experimental group were also able to successfully transfer and apply their argument skills across various genetics contexts. The authors concluded that the integration of explicit argument instruction into the genetics unit improved students' skills and/or quality of argumentation and their conceptual knowledge.

Similar results were obtained from a longitudinal study conducted by Yerrick (2000), who investigated the argumentation of five low-achieving high school students (refer to Section 4.3 for full details of the study). The unit incorporated explicit argumentation instruction, and utilised Toulmin's model to analyse students' discourse. Results indicated that students' skills of argument improved over the course of the intervention. Bell and Linn (2000) assessed middle school students' argument constructions during a Knowledge Integration Environment (KIE) project (refer to Section 4.3 for full details of the study). This software tool provided supported argumentation instruction by means of hints and prompts regarding the development and evaluation of arguments. Toulmin's model of argument was used to analyse student's discourse and results indicated that students' skills of argument improved over the course of the intervention.

Osborne et al.'s (2004a) comprehensive study which evaluated both students' and teachers' quality of argumentation (refer to Section 3.5.3 for full details of the study) over a two year period reported improvements in the quality of participants' argumentation as a result of an intervention which explicitly addressed various aspects of argumentation. The authors developed a set of curriculum materials which were utilised to support the learning of argumentation in the classroom. Using a framework for argument analysis which was adapted from Toulmin, the authors found that although the improvements in students' quality of arguments were not as large as expected, they did show some improvement. They highlighted the importance of including specific conceptual knowledge in the classroom to aid students in forming high quality arguments.

The above studies all support the notion that explicit (or supported) instruction in argumentation improves students' skills and/or quality of argumentation. In a similar vein, a study conducted by Jimenez-Aleixandre et al. (2000) found that a lack of explicit instruction in argumentation resulted in no substantial improvement in students' skills of argument. The authors investigated one class of year 9 science students over six, one-hour sessions devoted to genetics instruction. The aim of the study was to investigate the capacity of the students to develop and assess arguments during the course of the intervention. None of the students had received any previous instruction in argumentation, and the classroom teacher did not incorporate any explicit teaching of argumentation. Toulmin's argument framework was utilised to analyse classroom discourse. Results indicated that although the climate of the classroom was conducive to students expressing and defending their opinions, the quality and quantity of argumentation was generally low.

Conversely, two recent studies have reported improvements in students' argumentation skills and/or quality in studies where explicit instruction in argumentation was not provided. Jimenez-Aleixandre and Pereiro-Munoz (2002) investigated 38 high school students' decision-making and argumentation whilst engaged in a local, real-life issue concerning wetland environmental management. Students were required to assess the impact of a proposed development in the wetland adjacent to their school, thus providing an authentic problem for the students to investigate which had relevance to their daily lives. Students were required to collect evidence about the project, apply appropriate conceptual knowledge, and reach an informed decision about the issue. A debate was conducted with an outside expert present, to allow students to express their arguments and decisions on the issue. Student dialogue was analysed using frameworks developed by Toulmin and Walton. Results indicated that students' arguments displayed many similarities to those of the expert, including a comparable use of warrants, and the ability to base their decisions on empirical evidence.

Similar results were reported by Patronis et al. (1999) who investigated middle school students' argument construction whilst engaged in a local environmental issue. Students were required to develop an argument for dealing with the issue and provide supporting evidence for their position on the issue. Using Toulmin's framework to analyse their arguments, results indicated that students' patterns of argument were improved as a result of the intervention. The authors suggest that the utilisation of a local issue which was personally relevant to the students' daily lives contributed to their ability to construct informed arguments.

A closer analysis of the research reported in this section highlights some interesting findings. First, an important trend which emerged from the analysis of these studies was the impact of conceptual knowledge on learners' abilities to formulate arguments. Many of the studies that incorporated explicit argumentation instruction and reported improvements in learners' argumentation abilities, stressed the importance of integrating relevant conceptual knowledge when formulating arguments. As stated earlier, the relationship between conceptual knowledge and argumentation is the subject of considerable debate amongst researchers, and these findings lend support for the notion that a positive relationship exists between the integration of relevant conceptual knowledge and improvements in learners' argumentation abilities.

A second trend that emerged from an analysis of these studies was the impact of context on learners' abilities to formulate arguments. Both of the studies that reported improvements in learners' skills and/or quality of argumentation where no explicit instruction was utilised were conducted in socioscientific contexts that investigated local, real-life issues. As postulated by Patronis et al. (1999), personal relevance may have a significant effect on learners' abilities to construct informed arguments. The majority of the studies reported found that explicit instruction improved learners' skills and/or quality of argument (or similarly found that a lack of explicit instruction hindered the development of learners' skills and/or quality of argument) were conducted in scientific contexts. These findings suggest that there may be a relationship between the context of argumentation and the development of learners' skills and/or quality of argument. An analysis of the effect of differing contexts on learners' argumentation is considered in the following section.

3.5.3 Contexts for argumentation

This section will describe the two contexts for argumentation in science highlighted in the science education literature by Osborne et al. (2004a), namely 'scientific' and 'socioscientific' contexts. A detailed review of studies conducted in scientific and socioscientific contexts will be undertaken in the following chapter.

Scientific contexts for argumentation are concerned with the application of scientific reasoning to enable an understanding of the justification for hypotheses, the validity and limitations of scientific evidence, and the evaluation of competing models and theories (Giere, 1979). The development of scientific argumentation is an important aspect of scientific literacy as these types of arguments "expose the justification for belief in the scientific worldview and the underlying rationality that lies at the heart of science" (Osborne et al., 2004, p. 998). Engaging learners in argumentation in this context has been the subject of many studies conducted in science education (e.g., Abi-El-Mona & Abd-El-Khalick, 2006; Bell & Linn, 2000; Cavalli-Sforza, Weiner, & Lesgold, 1994; Clark & Sampson, 2006; Jimenez-Aleixandre et al., 2000; Yerrick, 2000).

Current trends in the science education community towards improving scientific literacy also provide the impetus for studies which aim to develop and improve learners' argumentation in socioscientific contexts. These contexts for argumentation are concerned with the application of scientific ideas and reasoning to an issue, and also invoke a consideration of moral, ethical and social concerns (Osborne et al., 2004a). Alternatively, the term 'socioscientific issues

(SSIs)' is commonly utilised in the science education literature to describe these contexts. SSIs can be best described as representing "complex social dilemmas based on applications of scientific principles and practice" (Sadler & Fowler, 2006, p. 2). Developing learners' abilities to engage in arguments of this nature is deemed important as issues and controversies which are relevant to the real world of the student are able to be evaluated in this context. Many of the studies that have investigated argumentation in this context have been conducted in the past five years (e.g., Bell & Lederman, 2003; Jimenez-Aleixandre & Pereiro-Munoz, 2002; Kolsto, 2006; Lewis & Leach, 2006; Sadler et al., 2004; Sadler & Fowler, 2006; Sadler & Zeidler, 2005; Zeidler et al., 2002; Zohar & Nemet, 2002).

Importantly, Osborne et al. (2004a) also point out that both scientific and socioscientific contexts for argumentation are related in that:

> … to engage in arguments about socioscientific issues pupils need to be able to distinguish arguments based on evidence from those based on values and beliefs. Hence, pupils need to understand the role and nature of evidence, issues of reliability, validity and risk. Developing young people's skills with the form and nature of argument will, therefore, enable them to distinguish speculative predictions, false associations, over-generalisations and recognise the limits to the 'certainty' of scientific knowledge. (p. 1015)

Thus, engaging learners in both scientific and socioscientific arguments is necessary to ensure learners are aware of the differing considerations each type of argument presents.

The previous section (refer to Section 3.5.4 for more details) highlighted a possible relationship between the context of argumentation and learners' skills and/or quality of argumentation. Findings from the studies reviewed indicated that explicit instruction positively correlated with improved argumentation skills and/or quality in studies conducted in scientific contexts, whereas some studies conducted in socioscientific contexts where participants were not provided with explicit argumentation instruction still reported improvements in learners' skills and/or quality of argumentation. Therefore, further research is needed to determine the influence of differing contexts on the development of learners' skills and/or quality of argumentation.

Osborne et al.'s (2004a) research which focused on enhancing the quality of teachers' and students' argumentation was the only empirical study identified in the literature which examined argumentation in both of these contexts. This longitudinal study examined the implementation of a learning environment that was designed to support argumentation instruction in junior high schools. The research was guided by the assumption that explicit instruction was a necessary precursor for developing high quality arguments. The teachers and students who took part in the intervention received explicit instruction in argumentation.

The study was conducted in two phases. In the first phase curriculum materials were developed to support teachers in developing their argumentation abilities, and their ability to implement argumentation in the classroom. The 12 science teachers involved in the study were observed as they attempted to implement their lessons in the classroom. Using a model of argument analysis adapted from Toulmin (refer to Section 3.4.3 for more details), the researchers noted that the majority of teachers showed improvements in the quality and use of argumentation over the duration of the intervention.

In the second phase of the study, 33 classroom lessons were observed to determine if students' quality of argumentation developed over the course of the intervention. These lessons were taught by a sample of teachers from the first phase of the study, and each of the classes of year 8 students who were assigned to the experimental groups were taught a minimum of nine argument-based lessons. A comparison group was taught similar lessons at the commencement and conclusion of the year, without the inclusion of argument-based instruction. Lessons with the experimental group classes were conducted approximately once a month over the duration of the academic year. The first and last lessons in the sequence focused on argumentation in a socioscientific context, with the remaining seven lessons focused on argumentation in scientific contexts. Using a model of argument analysis adapted from Toulmin, findings suggested that, in general, there was a modest improvement in the quality of students' arguments. Other important findings indicated that the level of argumentative discourse in scientific contexts was significantly lower than the level of argumentative discourse in socioscientific contexts. The authors suggested that the initiation of argumentation in scientific contexts is more difficult for both students and their teacher, and a lack of conceptual knowledge may limit students' and teachers' abilities to engage in argumentation on scientific topics, which often require specific conceptual knowledge about the topic. They suggested that many students possess some understanding and knowledge about socioscientific topics formed through their own life experiences, which may enable them to apply these concepts to their reasoning about socioscientific issues. The authors concluded that students should be provided with relevant concepts and evidence to enable them to engage in higher quality argumentation.

It is important to note, however, that results indicated that the quality of argumentation in not only the experimental groups, but also the comparison group, improved slightly over the course of the intervention. Both groups exhibited similar quality of argumentation at the commencement of the intervention. The authors concluded that improving students' skills and quality of argumentation is a long-term process that requires an explicit instruction approach. The implications of this study suggest that learners need to be explicitly guided in developing and applying skills of argument in both scientific and socioscientific contexts, and that the application of relevant conceptual knowledge may be needed (particularly in scientific contexts) to ensure learners are able to engage in argumentation effectively.

The identification of explicit argumentation instruction, context of argumentation, and conceptual knowledge as influential factors affecting learners' skills and/or quality of argumentation has been established in this chapter. The following chapter will provide a detailed overview of an emerging area of research exploring NOS and argumentation.

3.6 Summary

The purpose of the review was to situate this study within the broader context of argumentation research, and critically analyse the various modes and contexts of argumentation instruction. The term 'argumentation' has a multitude of meanings in the research literature, some of which include: (a) "…juxtaposition of two opposing assertions" (Kuhn, 1991, p. 12), (b) "…interactive dialogue in which people reason together on a disputed subject" (Walton, 1996, p. 26), and (c) "the coordination of evidence and theory to support or refute an explanatory conclusion, model, or prediction" (Suppe, 1998). Arguments that stem from the informal reasoning domain can be generally categorised into two different, but related forms or types, rhetorical and dialectical arguments.

Rhetorical arguments are "oratorical in nature and are represented by the discursive techniques employed to persuade an audience. In contrast to the other forms of argument where a consideration of the evidence is paramount, they stress knowledge and persuasion" (van Eemeren et al., 1996, p. 11). On the other hand, dialectical arguments generally take place during discussions and involve reasoning with premises that do not necessarily appear to be true. Science educators such as Driver et al. (2000) have posited that these types of arguments can be effectively utilised in the science classroom to enable students to develop their argumentation abilities.

Various argumentation models have been developed and utilised in the field of science education, with the dominant one being Toulmin's model of argumentation. His informal model focuses on the functional relationships amongst elements of an argument, and allows the structure of an argument to be analysed. A number of limitations or difficulties have been highlighted by various researchers who have sought to apply Toulmin's model of argumentation to student dialogue. Some of these difficulties include (a) the different ways components of the model, such as data, qualifiers, claims, etc., can be interpreted, (b) an inability to assess the correctness or quality of an argument, (c) a failure to consider contextual factors and conceptual knowledge, and (d) an inability to analyse lengthy or complex argument structures.

Due to the limitations listed above, some science educators have proposed alternative frameworks to analyse arguments. The majority of these frameworks have adapted Toulmin's basic framework for argumentation and provide an analytical account of argumentation (e.g., Alexopoulou & Driver, 1997; Eichinger et al., 1991; Jimenez-Aleixandre et al., 2000; Kuhn, 1993; Kuhn et al., 1997; Osborne et al., 2004a; Pontecorvo, 1987; & Zohar & Nemet, 2002). These frameworks have added to our knowledge about how learners construct arguments and engage in argumentative practices, but they do not allow a consideration of how learners' subject matter knowledge impacts the arguments they construct, or if this subject matter knowledge changes as a result of engaging in argumentation.

Other argumentation frameworks have been developed that are not adapted from Toulmin's model. Many of these frameworks (Clark & Sampson, 2006; Driver et al., 2000; Sandoval & Millwood, 2005) assess both the structure and the conceptual quality of the arguments learners construct. These studies highlight the complexity of examining learners' argumentative discourse, and provide evidence to suggest that the application of structural frameworks such as Toulmin's model may not enable a full evaluation of argumentative discourse to occur.

An examination of previous studies conducted in the field of science education that have utilised argumentation in their design has highlighted the following general findings: (a) students generally have poor argumentation skills with specific difficulties such as ignoring data and warrants, introducing inferences and reinterpretations, jumping to conclusions, and an inability to evaluate counter-evidence, commonly reported; (b) most classrooms are teacher dominated, with students given few opportunities to learn about, or engage in argumentation; (c) teachers generally do not possess adequate skills of argumentation to effectively convey to their students; (d) age and previous knowledge may influence argumentation skills; and (e) the relationship between conceptual knowledge and argumentation is complex, with further research needed to ascertain whether the integration of conceptual knowledge improves argumentation skill and/or quality.

An important area of recent research in the field seeks to investigate the relationship between explicit instruction in argumentation and learners' skills and/or quality of argumentation. A general recommendation which has emerged from recent science education literature (e.g., Kuhn, 1993; Hogan & Maglienti, 2001; Zohar & Nemet, 2002) supports the notion that explicit instruction in argumentation is a necessary prerequisite for enabling the development of learners' skills and/or quality of argument. Explicit instruction in this context refers to the direct teaching of various aspects of argumentation including instruction pertaining to the various definitions, structure, function, and application of arguments, and the criteria used to assess the validity of arguments.

Two important findings were identified from an analysis of research conducted in this area. First, an important finding that emerged from the analysis of these studies was the impact of conceptual knowledge on learners’ abilities to formulate arguments. Many of the studies that incorporated explicit argumentation instruction and reported improvements in learners’ argumentation abilities, stressed the importance of integrating relevant conceptual knowledge when formulating arguments.

Another finding that emerged from an analysis of these studies was the impact of context on learners’ abilities to formulate arguments. Osborne et al. (2004a) have highlighted that two distinct contexts for argumentation in science exist, namely, scientific and socioscientific contexts. Scientific contexts for argumentation are concerned with the application of scientific reasoning to enable an understanding of the justification for hypotheses, the validity and limitations of scientific evidence, and the evaluation of competing models and theories (Giere, 1979). Socioscientific contexts for argumentation are concerned with the application of scientific ideas and reasoning to an issue, and also invoke a consideration of moral, ethical and social concerns. Engaging learners in argumentation in both contexts is deemed necessary to ensure they are made aware of the differing considerations each type of argument presents.

The majority of studies conducted in scientific contexts that reported improvements in learners’ skills and/or quality of argumentation utilised explicit argumentation instruction, whereas both of the studies that reported improvements in learners’ skills and/or quality of argumentation where no explicit argumentation instruction was utilised were conducted in socioscientific contexts. These findings suggest that there may be a relationship between the context of argumentation and the development of learners' skills and/or quality of argument.

Osborne et al.'s (2004a) research which focused on enhancing the quality of teachers' and students' argumentation was the only empirical study identified in the literature which examined argumentation in both scientific and socioscientific contexts. Implications drawn from this study suggest that students need to be explicitly guided in developing and applying skills of argument in both scientific and socioscientific contexts, and that the application of relevant conceptual knowledge may be needed (particularly in scientific contexts) to ensure students are able to engage in argumentation effectively.

This review has identified explicit argumentation instruction, context of argumentation, and conceptual knowledge as influential factors affecting learners' skills and/or quality of argumentation. The following chapter will examine studies conducted in science education that have examined NOS and argumentation.

CHAPTER 4 – NATURE OF SCIENCE AND ARGUMENTATION RESEARCH

4.1 Introduction

This chapter will provide a detailed overview of an emerging area of research exploring NOS and argumentation. The purpose of this review is to identify trends in the current research base, and provide evidence to support the inclusion of explicit NOS and argumentation instruction in scientific and socioscientific contexts, to aid in developing students' and teachers' views of NOS.

A search of the literature revealed nine studies that have been conducted in this area. Four of these studies have been conducted in scientific contexts (Bell & Linn, 2000; Kenyon & Reiser, 2006; Sandoval & Millwood, 2005; & Yerrick, 2000), four studies were conducted in socioscientific contexts (Bell & Lederman, 2003; Sadler et al., 2004; Walker & Zeidler, 2004; & Zeidler et al., 2002), and one study was conducted in a historical context (Ogunniyi, 2006). A summary of these studies is provided in Table 4.1.

This chapter will commence with a rationale for investigating possible links between NOS and argumentation. It will be followed by an examination of studies that have investigated NOS and argumentation in scientific contexts. The next section will examine studies that have investigated NOS and argumentation in socioscientific contexts. Historical contexts for argumentation will then be considered, followed by a summary of the major findings from the literature. The

Table 4.1 *Empirical studies investigating NOS and argumentation*

Study	Aim	Context	Participants	NOS instruction implemented	Argumentation instruction implemented	Results
Yerrick (2000)	Assess students' skills of argumentation	Scientific	High school students *(N=5)*	No	Yes - Explicit	Argumentation and NOS improved Views of some aspects of NOS reflected in arguments
Bell & Linn (2000)	Investigate relationship between students' NOS views and their arguments	Scientific	Middle school students *(N=172)*	No	Yes - Supported	Argumentation and NOS improved
Sandoval & Millwood (2005)	Examine the influence of epistemological views about argumentation on inquiry practices	Scientific	High school students *(N=87)*	No	Yes - Supported	Naïve views of NOS may constrain students engagement in argumentation
Kenyon & Reiser (2006)	Investigate the application of epistemological views to evaluate argumentation	Scientific	Middle school students *(N=64)*	Yes - Explicit	Yes - Explicit & supported	Applying NOS views aided argument evaluation
Zeidler, Walker, Ackett, & Simmons (2002)	Examine the relationship between NOS views and evidence that challenged beliefs about a SSI	Socioscientific	High school students to preservice elementary teachers *(N=248) (n=82)*	No	No	Views of some aspects of NOS reflected in arguments No improvement in argumentation
Sadler, Chambers, & Zeidler (2004)	Examine views of NOS in response to a SSI	Socioscientific	High school students *(N=84)*	No	No	Views of some aspects of NOS reflected in arguments Some aspects of NOS influenced students' reasoning on the issue
Bell & Lederman (2003)	Investigate the role of NOS in decision-making about SSIs	Socioscientific	University professors and research scientists *(N=21)*	No	No	NOS views did not influence their reasoning on issues
Walker & Zeidler (2004)	Investigate the role of NOS in decision-making	Socioscientific	High school students *(N=36)*	Yes - Explicit	Yes - Supported	NOS views did not influence their reasoning on the issue NOS improved No improvement in argumentation
Ogunniyi (2006)	Examine the effectiveness of an argument-based, reflective NOS course on NOS views	Historical	Inservice science teachers *(N=3)*	Yes - Explicit	Yes - Explicit	NOS improved

chapter will conclude with an overview of the contribution of this study, including the purpose of the study, and the research questions to be addressed.

4.2 Rationale

Recent research has suggested that a possible relationship exists between learners' views of NOS and scientific argumentation (Bell & Linn, 2000; Kenyon & Reiser, 2006; Kuhn & Reiser, 2006; Sampson & Clark, 2006; Sandoval & Millwood, 2005; Yerrick, 2000). Research in argumentation conducted by Sampson and Clark (2006) indicates that although explicit instruction in argumentation has aided learners in becoming more skilled at argumentation, major changes have not occurred, and many learners still do not exhibit adequate argumentative abilities. They propose that research attempts must now focus on the influence of learners' epistemological ideas on their scientific argumentation, and hypothesise that the difficulties learners have in participating in scientific argumentation may be explained by examining their epistemological commitments related to the role of argumentation in scientific inquiry. They propose that these difficulties arise because learners' epistemological commitments are not the same as those of the scientific community, and without informed NOS views, learners may not realise claims are open to challenge and refutation, and require the support of empirical evidence.

Sampson and Clark (2006) propose that the epistemological commitments learners hold influence how they participate in scientific argumentation, and suggest that improving learners' skills of argument will involve changing their epistemological views in addition to developing pedagogical practices that support and promote argumentation in the classroom. They conclude that little is known about how learners' epistemological views influence how they construct and evaluate arguments, and they have recently developed and validated a new survey instrument, the 'Nature of Science as Argument Questionnaire (NSAAQ)' that has been designed to identify learners' epistemological views relevant to argumentation. It is important to note that these authors have not empirically tested this claim, and they suggest that studies are needed to provide empirical evidence to support or refute this assumption.

Kuhn and Reiser (2006) hold a similar view and propose that learners' epistemological ideas may influence how they participate in scientific argumentation. They assert that if learners hold naïve views of scientific knowledge as a body of absolute facts, they are unlikely see the need to engage in debates about scientific issues. Recent studies conducted by Kenyon and Reiser (2006) and Sandoval and Millwood (2005) are underpinned by the assumption that learners' views of NOS influence how they engage in scientific argumentation. The authors of these studies propose that if learners hold naïve views of NOS, they will display limited abilities to engage in scientific argumentation. Results from these studies suggest a possible relationship between learners' views of NOS and their engagement (or lack of engagement) in scientific argumentation (refer to Section 4.3 for more details).

Other researchers have viewed the relationship between NOS and scientific argumentation in a slightly different manner. Studies conducted by Bell and Linn (2000) and Yerrick (2000) are guided by the assumption that engaging learners in the process of argumentation may improve their understandings of NOS. Results from these studies provide some evidence to suggest that engaging learners in scientific argumentation may lead to improvements in their views of NOS (refer to Section 4.3 for more details).

Research conducted in socioscientific contexts has also highlighted possible links between learners' NOS views and their engagement in argumentation in socioscientific contexts (Kolsto et al., 2006; Lewis & Leach, 2006; Sadler et al., 2004; Walker & Zeidler, 2004; Zeidler et al., 2002; Zeidler et al., 2005), although one study (Bell & Lederman, 2003) failed to find a relationship between participants' views of NOS and their socioscientific reasoning (refer to Section 4.4 for more details). It is important to note that many studies conducted in socioscientific contexts examine students' decision-making processes, and not necessarily their skills or quality of argumentation.

Zeidler et al. (2005) propose that students' views of NOS influence the manner in which they view, cite and use evidence that may support or oppose their pre-existing beliefs about particular socioscientific issues. They assert that students who hold naïve views of NOS may not regard scientific content knowledge as an important aspect of their decision-making when engaged in socioscientific reasoning, and that these students may misinterpret available data and claims to support their own pre-existing position on an issue. They recommend that students need to be provided with guidance in applying their NOS understandings during the decision-making process, and learn to critically evaluate scientific claims, some of which may oppose their pre-existing views. Although Zeidler et al., (2005) did not empirically test their assertions, research conducted by Bell and Lederman (2003) and Walker and Zeidler (2004) highlights the importance of providing guidance to enable learners to apply their views of NOS to their reasoning in socioscientific contexts (refer to Section 4.4 for more details).

Kolsto et al. (2006) also support the view that understandings of NOS are needed to allow students to engage with socioscientific issues. They stress that the ability to critically evaluate socioscientific issues is an essential component of scientific literacy, and students need to learn about the methodological, social, and institutional aspects of the scientific enterprise. These assertions are supported by Lewis and Leach (2006) who highlighted the importance of providing explicit NOS instruction to enable students to effectively engage in socioscientific reasoning. They suggested that classroom instruction directed at developing students' argumentation skills, and moral and ethical reasoning abilities, would allow students to engage in socioscientific reasoning more effectively. Further studies are needed to examine the influence of these factors on learners' views of NOS and/or argumentation in socioscientific contexts.

In conclusion, this section has provided a rationale for investigating possible links between NOS and argumentation. It is important to note that there is only a modest amount of evidence in the science education literature to empirically support a relationship between NOS and argumentation. Further empirical studies are needed to provide additional support (or refutation) of this assertion. The following section will discuss the four empirical studies identified in the literature that have investigated NOS and argumentation in scientific contexts.

4.3 Studies conducted in scientific contexts

The first study identified in the literature that provided empirical evidence of a possible relationship between NOS and argumentation was conducted by Yerrick (2000), who investigated five low achieving high school students' participation in a general science unit which focused on argument construction, question generation, and experimental design. The researcher was interested in assessing changes in students' abilities to construct arguments within scientific contexts. He explicitly taught skills of argumentation to the students over the duration of the intervention, implemented in an open-inquiry setting. The curriculum was designed to allow students to collect and analyse evidence, offer explanations, pose hypotheses, and propose models about everyday events related to science. Students then designed and implemented group projects to test their hypotheses. No explicit NOS instruction was implemented during the intervention.

Over an 18-month period, videotaped science lessons, and pre- and post-interviews were used as data sources. Data analysis utilised Toulmin's model of argument analysis, and post-study results indicated that students' views of the tentative nature of scientific knowledge, the use of scientific evidence, and the source of scientific authority, developed over the duration of the study to be closely aligned with informed views of these NOS aspects. The results of this study provide some support for the notion that engaging students in scientific argument and inquiry may result in improvements in their views of some aspects of NOS, although this was not a specific aim of the study. Students' views of the above aspects of NOS were also reflected in their arguments, and some improvements in their skills of argument were also evident.

Bell and Linn (2000) assessed 172 middle-school students' argument constructions during a Knowledge Integration Environment (KIE) debate project. The project was designed to encourage a better understanding of students' views of science and to investigate the relationship between the arguments students construct and their views of NOS. This study was guided by the assumption that arguments formulated by students will reflect aspects of their views about NOS. Supported argumentation instruction was implemented in the study via a software tool designed to make the structure of an argument visible to students. The tool also provided hints and prompts about various aspects of argumentation to guide students in developing and evaluating arguments from differing perspectives.

At the commencement of the project, students were provided with two contrasting statements about light propagation, and were then asked to align themselves with one of these two positions based on their own personal view. During six classroom lessons, pairs of students investigated light propagation by collecting and analysing multimedia evidence gained from both scientific and everyday data sources. Students then constructed and/or refined their arguments to support one position or the other. No explicit NOS instruction was implemented during the intervention.

Toulmin's argument framework was utilised to code data and to develop explanations for each piece of evidence. A class discussion was held at the conclusion of the project where pairs of students presented their arguments and reflected on questions and issues which arose during the project. Students also completed a multiple choice survey about their views of NOS (adapted from Davis, 1998) at the commencement and conclusion of the study.

Results indicated that students with a dynamic or developed understanding of NOS created more complex arguments which integrated both unique warrants and an increased frequency of warrant usage. They also included more conceptual frames in their arguments. Results also indicated that students' knowledge integration and skills of argumentation improved over the duration of the study. The authors state that their study provides some evidence for the claim that engaging students in the process of argumentation improves their understanding of NOS. They support this assertion by noting that post-test results of participants' NOS views indicated an improvement in NOS understandings.

The following study was informed by a growing body of literature that examines epistemology, inquiry and argumentation. Researchers working in this area propose that engaging learners in inquiry tasks such as constructing, developing, defending and evaluating scientific arguments and explanations, requires the application of epistemological understandings to support epistemic decisions (Hogan, 2000; Kenyon & Reiser, 2006; Sandoval, 2005).

A recent study was conducted by Sandoval and Millwood (2005) who investigated the quality of 87 high school biology students' written explanations about natural selection using a software tool designed to support scientific inquiry and guide students in constructing theory-based scientific explanations. They sought to examine the influence of students' epistemological views about argumentation on their inquiry practices. Their research was guided by the assumption that implicit epistemological ideas are reflected in students' selection and use of data in their scientific explanations.

No explicit NOS instruction was provided to the students, nor were their pre- and post-intervention views of NOS assessed. The software tool successfully provided supported argumentation instruction via scaffolds that allowed students to construct logical arguments. Nevertheless, students had difficulties citing sufficient data to support claims and also had difficulties providing warrants for some claims.

Other results indicated that there was a relationship between conceptual knowledge and data citation, although many students viewed data as 'self-evident,' and did not provide an explanation of the data in their scientific explanations. The authors proposed that students may not distinguish claims from data, and may believe that data are an objective representation of scientific knowledge, not subject to interpretation. Implications from this research suggest that students who display naïve views of NOS may not provide explanations or warrants for their claims, thus influencing their ability to engage in scientific argumentation effectively.

Kenyon and Reiser (2006) outlined a functional approach to applying relevant epistemological understandings to the inquiry practices of 64 middle school students during an eight week project-based unit on ecology. Their functional approach for teaching NOS focused on encouraging students to use their epistemological views to guide their investigations whilst engaged in scientific inquiry tasks. A supported argumentation instructional approach was utilised in the study that involved students using a software tool to examine data, and develop explanations and arguments. Students also received explicit argumentation instruction during the study.

Although the authors supported the use of an explicit, reflective approach to NOS instruction, the results of a previous study (Kenyon & Reiser, 2005) highlighted the limitations of relying solely on an explicit, reflective approach as this approach did not allow students to recognise the relevancy of NOS understandings, nor utilise these understandings when engaged in scientific decision-making. Hence, these findings prompted the design of the present study. Two design strategies were documented that were developed to support students' use of epistemologies in their inquiry tasks. The first design strategy was to use argumentation as a context to 'create a need' for students to apply their epistemological understandings to develop and evaluate scientific explanations.

Their second design strategy, termed 'providing scaffolds,' was developed to support students' conceptual understanding of the various parts of a scientific explanation. This framework was further enhanced by asking students to develop their own epistemological criteria to build and evaluate their scientific explanations. Results indicated that using the set of student-developed epistemological criteria aided students 'creating a need' to engage in argumentation and make decisions, and helped them to evaluate the quality of scientific explanations. The integration of classroom debates and argument jigsaws (whereby pairs of students compare and justify ideas, and reach a group consensus) allowed students to apply their epistemological criteria to guide and support their arguments.

The authors concluded that students need to recognise the relevancy of epistemological ideas and their application to their decision-making. The functional approach to teaching about NOS developed in this study was relatively successful in allowing students to directly use and apply their epistemological understandings during scientific inquiry activities.

In summary, the four studies reviewed in scientific contexts highlight some important trends. The two empirical studies that assessed participants' argumentation and views of NOS (Bell & Linn, 2000; Yerrick, 2000), reported improvements in both participants' argumentation and their views of NOS. Both of these studies implemented explicit or supported argumentation instruction that has previously been shown to aid in developing participants' skills and/or quality of argumentation in scientific contexts (refer to Section 3.5.2 for more details). Interestingly, although neither of these studies incorporated explicit NOS instruction, participants' views of NOS improved over the duration of the studies. On the basis of these findings a proposition could be forwarded that the integration of explicit NOS instruction may *not* be considered essential in scientific contexts where explicit argumentation instruction is provided. As this assertion is contrary to a large body of research in the field of NOS that supports the notion that explicit NOS instruction is necessary to aid in developing students' and teachers' views of NOS (refer to Section 2.5.2 for more details), one must exercise considerable caution in forwarding this claim. Thus, further research is needed to investigate this proposition.

The other two reviewed studies (Kenyon & Reiser, 2006; Sandoval & Millwood, 2005) did not directly assess participants' argumentative abilities or views of NOS. These studies were concerned with examining the influence of participants' views of NOS on scientific argumentation. Sandoval and Millwood (2005) suggested that students who display naïve views of NOS may not engage in scientific argumentation effectively, as they may not recognise the importance of providing explanations or warrants for their claims. Kenyon and Reiser (2006) suggested that students need to recognise the relevancy of epistemological ideas and their application to their decision-making. The results of their study indicate that the application of NOS ideas aided students' abilities to evaluate scientific arguments. Implications from the findings of these two studies suggest that a relationship exists between learners' views of NOS and their engagement (or lack of engagement) in scientific argumentation. Again, one must exercise caution in forwarding this claim as learners' views of NOS and skills and/or quality of argumentation were not directly assessed in either of these studies. Additional studies which provide an assessment of learners' NOS views and skills and/or quality of argumentation are needed to provide empirical evidence to lend support for this assertion.

The following section will discuss the four empirical studies identified in the literature that have investigated NOS and argumentation in socioscientific contexts.

4.4 Studies conducted in socioscientific contexts

The first empirical study to emerge in a socioscientific context that investigated NOS and argumentation was conducted by Zeidler et al. (2002). The study was designed to investigate the relationship between students' views of NOS and their reactions to evidence that challenged their beliefs about a socioscientific issue. The authors proposed that the inclusion of socioscientific issues that require students to engage in critical discussions and debates may reveal relevant NOS aspects to students as these types of scenarios provide a platform for considering both ethical and moral issues.

Participants consisted of 41 pairs of students selected from an initial subject pool of 248 students, ranging from junior (year 9 and 10) high school science students to preservice elementary teachers. Students were selected to provide contrasting ethical viewpoints on the issue of animal rights. Data were collected from students' responses to questionnaires (including an open-ended NOS questionnaire previously utilised by Lederman et al., 1999), written responses to a socioscientific scenario on animal rights, and interviews. A framework of argument analysis was utilised based on dialogic reasoning (Gee & Green, 1998). Students received no explicit instruction in NOS or argumentation during the intervention.

Data analysis indicated that, in a few cases, students' views of NOS were reflected in the arguments they presented on a moral and ethical issue. The aspects of NOS that were reflected in students' arguments included the social and cultural NOS, and the empirical NOS. The researchers noted that the use of anomalous data and in-depth questioning during the study allowed the interviewers to explore participants' NOS beliefs, and they recommend that future studies explicitly incorporate these techniques to facilitate participants' understandings of NOS. Results also indicated that many participants' responses were based on personal opinions and failed to integrate relevant scientific evidence.

Other results indicated that participants' argumentation skills did not appear to improve as a result of investigating the socioscientific issue, although these skills were not directly assessed in the study. Participants' NOS views were not assessed at the conclusion of the study, so no assertions can be made with regard to the possible development of these views. The authors recommended that classroom teachers need to develop competent reasoning skills so that they may confidently guide their students during the process of investigating NOS and engaging in socioscientific issues. As such, they propose that teacher preparation programs need to expose their students to both explicit instruction about NOS and argumentation.

A similar study was conducted by Sadler et al. (2004) who also sought to examine students' views of NOS in response to a socioscientific issue. The researchers were interested in how students interpret and evaluate contradictory evidence when engaged in a global warming scenario. The study also sought to examine how students interpret and evaluate contradictory evidence in a socioscientific context in terms of the persuasiveness and scientific merit of the evidence presented. Eighty-four high school biology students across four classes were involved in the study. Each student was presented with a scientific report on global warming that consisted of two differing perspectives on the issue, and a series of open-ended questions which were designed to elicit students' views of aspects of NOS, and the factors that influence their reasoning on the issue. Follow up interviews were conducted with 30 of the students to allow clarification and elaboration of responses. Students received no explicit instruction in NOS or argumentation during the study, nor were students argumentation skills assessed prior to, or at the conclusion of the study.

Results indicated that students' exhibited diverse views of the three NOS aspects examined in the study, namely, the empirical, tentative and social NOS. In general, students displayed an understanding of both the tentative and social NOS, although just under half of the students displayed naïve views of the empirical NOS. The authors recommend that explicit NOS instruction is necessary to ensure students are provided with the opportunity to form developed views of NOS. They also state that engaging students in the global warming issue was an effective means of investigating and revealing their views of the three NOS aspects. Other important findings indicated that students' views of the social NOS considerably influenced their reasoning and argumentation in the socioscientific context, as did their views on the persuasiveness and scientific merit of the reports.

A recent study which challenged the findings of Sadler et al. (2004) was conducted by Bell and Lederman (2003) who also investigated the role of NOS in decision-making about socioscientific issues. The underlying rationale for the study was based on the premise that if there is a relationship between NOS and decision-making, then participants with diverse views of NOS should exhibit different reasoning about socioscientific issues. Participants were purposively selected to provide divergent views of NOS. The sample consisted of 21 university professors and research scientists, who were placed in two groups representing disparate views of NOS.

The groups were formed after participants completed an open-ended NOS questionnaire (VNOS-B) which assessed their views of various aspects of NOS. The participants were also administered a second open-ended questionnaire that was designed to obtain information about their decision-making in a variety of socioscientific contexts. All of the participants were interviewed after the administration of the questionnaires. The participants did not receive any explicit instruction in NOS or argumentation, nor were their skills of argumentation assessed.

The Decision Making Questionnaire (DMQ) consisted of a set of four different socioscientific scenarios related to real-world issues. After reading each of the scenarios, the participants were required to respond to three to five questions about the scenarios that were designed to elicit the factors and reasoning that influenced their decisions. Results indicated that participants' NOS views were not a significant contributing factor in the decisions reached by the participants in either group in each of the four scenarios. The participants' reasoning patterns tended to focus on personal, social and political aspects of the issue, with little reference to scientific evidence as a contributing factor in their reasoning.

The authors concluded that NOS did not appear to significantly influence the decision-making of participants when engaged in socioscientific issues in this study. Importantly, they noted that the sample used in this study was not representative of the general public, and proposed that further research is needed to examine this relationship with populations of interest, such as science teachers. They recommended that learners need to be explicitly instructed on how to utilise and apply their NOS views when engaged in decision-making on issues.

Another recent study reported by Walker and Zeidler (2004) also sought to examine the role of NOS in decision-making about a socioscientific issue. The purpose of the study was to assess how a web-based instructional unit on genetically modified foods (GMFs) might elicit, reveal, and develop students' understanding of NOS, and inform their decision-making. The study was designed to incorporate specific science content knowledge about GMFs, explicit NOS instruction, and supported argumentation instruction in the form of guidance in evidence selection. The students did not receive any instruction on the structure or nature of arguments, and the study utilised the Web-based Inquiry Science Environment (WISE) to implement the classroom instruction over seven classroom sessions.

Participants consisted of 36 high school science students from two classes. Prior to the intervention, students completed a NOS questionnaire (Rubba, 1977) to assess their views of some aspects of NOS. No assessment was made of students' skills of argumentation prior to the intervention, although none of the students had previous experience in formulating arguments or debating. At the commencement of the unit, the students took part in a teacher-led lesson which included explicit instruction about the relevant aspects of NOS they were likely to explore during the GMF controversy. During the unit, various questions about relevant aspects of NOS were embedded within the online environment. Many of these questions were modified from the Science-Technology-Society Survey (Aikenhead & Ryan, 1992).

Students were also required to participate in a classroom debate about the issue, which required them to collect, organise and analyse supporting evidence for their arguments. They were guided through this process within the WISE environment. The authors noted that the intervention was designed to allow students to select aspects of NOS and pieces of evidence about GMFs to construct and support their positions on the issue, thus ensuring that students were not forced to consider aspects of NOS in their decision-making which they did not consider relevant. Thus, the students did not receive any explicit guidance in considering how various aspects of NOS might impact or affect the decisions they made on the issue. Toulmin's argument framework was used to assess the quality of students' argumentation.

At the conclusion of the intervention, student pairs took part in semi-structured interviews utilising questions from an open-ended NOS questionnaire (VNOS, Lederman et al., 2001) to assess their views of NOS. Results indicated that students' views of NOS developed over the duration of the study, and were aligned with dynamic views of NOS at the conclusion of the study. Results regarding the nature of the relationship between students' NOS views and their decision-making indicated that NOS was not explicitly referred to in their arguments, although the issue-based activity did enable their views to be elicited and revealed. Other results indicated that, in general, the students were not able to develop sound, evidence-based arguments, with an analysis of dialogue revealing several examples of hypothetical, moral, and fallacious reasoning.

The authors proposed that the students' newly acquired, but limited conceptual knowledge about the controversy constrained their ability to develop sound arguments, and proposed that more time and explicit instruction in argumentation is necessary to develop students' abilities to construct sound arguments. They also recommended that teachers need to develop the necessary pedagogical skills to guide their students in effectively applying their NOS understandings to socioscientific issues.

In summary, the four studies reviewed in socioscientific contexts highlight three important trends. First, results from the two studies (Zeidler et al., 2002; Walker & Zeidler, 2004) that assessed participants' argumentation skills and/or quality, indicated that participants' argumentation was poor, and did not improve over the duration of the studies. Neither of these studies implemented explicit argumentation instruction [although Walker & Zeidler (2004) did use a supported instructional approach], and the authors recommended that explicit argumentation instruction is necessary to aid in developing participants' skills and quality of argumentation.

Second, only one of the reviewed studies (Walker & Zeidler, 2004) assessed the development of participants' views of NOS. Explicit NOS instruction was implemented in the study, and results indicated that participants' views of some aspects of NOS shifted to dynamic views of NOS. This finding is aligned with a significant body of NOS research that has shown the effectiveness of explicit approaches in developing participants' NOS views (refer to Section 2.5.2 for more details).

Third, a recommendation that stemmed from all of the reviewed studies focused on the importance of providing explicit NOS instruction in future studies. In particular, Bell and Lederman (2003), and Walker and Zeidler (2004), suggested that students require explicit instruction in using and applying their NOS understandings to socioscientific issues, as results from both of these studies reported that students' NOS views did not influence their reasoning or arguments. Conversely, Sadler et al. (2004) found that students' views of NOS did influence their reasoning and arguments, and Zeidler et al. (2002) found that participants' views of some aspects of NOS were reflected in their arguments. Thus, further research is needed to clarify this relationship. The following section will outline one recent study identified in the research literature that has examined NOS and argumentation in a historical context.

4.5 Studies conducted in historical contexts

A search of the research literature revealed one empirical study conducted in a historical context that examined NOS and argumentation. Ogunniyi (2006) examined the effectiveness of an argumentation-based, reflective nature of science course on inservice science teachers' views of NOS, in which argumentation was explicitly emphasised. Explicit NOS instruction was also provided in the course. The study investigated the utilisation of argumentation as a reflective tool in developing valid views of NOS. Preliminary results were provided for three participants who were enrolled in a single semester course that included instruction in the psychology and sociology of science, and the history and philosophy of science. A Nature of Science Questionnaire (NOSQ), interview schedules, and reflective essays were utilised to assess teachers' understandings of NOS. Results indicated that teachers' views of NOS improved from a naïve view of science to a dynamic view of science.

The author concluded that the major improvement in the teachers' views of NOS at the end of the course provide evidence of the effectiveness of a course which emphasises explicit argumentation instruction and consideration of historical, philosophical and sociological aspects of science.

Thus, the integration of explicit NOS and argumentation instruction aided in the development of participants' views of NOS in this study. It is important to note that preliminary results only were reported in this study, so care must be taken not to over-interpret these findings. Further empirical studies conducted in historical contexts are needed to lend support for the assertions presented in this study.

4.6 Summary

The purpose of this review was to identify trends in current research investigating NOS and argumentation. Nine empirical studies have been conducted in this area (Bell & Lederman, 2003; Bell & Linn, 2000; Kenyon & Reiser, 2006; Ogunniyi, 2006; Sadler et al., 2004; Sandoval & Millwood, 2005; Walker & Zeidler, 2004;

Yerrick, 2000; & Zeidler et al., 2002) in scientific, socioscientific, and historical contexts. A summary of these studies is provided in Table 4.1.

A rationale was outlined for investigating possible links between NOS and argumentation in this chapter. Recent research has suggested that a possible relationship exists between learners' views of NOS and scientific argumentation (Bell & Linn, 2000; Kenyon & Reiser, 2006; Kuhn & Reiser, 2006; Sampson & Clark, 2006; Sandoval & Millwood, 2005; Yerrick, 2000). Sampson and Clark (2006) propose that the epistemological commitments learners hold influence how they participate in scientific argumentation, and suggest that improving learners' skills of argument will involve changing their epistemological views in addition to developing pedagogical practices that support and promote argumentation in the classroom. Kuhn and Reiser (2006) hold a similar view and propose that learners' epistemological ideas may influence how they participate in scientific argumentation. Recent studies conducted by Kenyon and Reiser (2006) and Sandoval and Millwood (2005) are underpinned by the assumption that learners' views of NOS influence how they engage in scientific argumentation. Results from these studies suggest a possible relationship between learners' views of NOS and their engagement (or lack of engagement) in scientific argumentation.

Other researchers have viewed the relationship between NOS and scientific argumentation in a slightly different manner. Studies conducted by Bell and Linn (2000) and Yerrick (2000) are guided by the assumption that engaging learners in the process of argumentation may improve their understandings of NOS. Results from these studies provide some evidence to suggest that engaging learners in scientific argumentation may lead to improvements in their views of NOS.

Research conducted in socioscientific contexts has also highlighted possible links between learners' NOS views and their engagement in argumentation in socioscientific contexts (Kolsto et al., 2006; Lewis & Leach, 2006; Sadler et al., 2004; Walker & Zeidler, 2004; Zeidler et al., 2002; Zeidler et al., 2005), although one study (Bell & Lederman, 2003) failed to find a relationship between participants' views of NOS and their socioscientific reasoning. Zeidler et al. (2005) propose that students' views of NOS influence the manner in which they view, cite and use evidence that may support or oppose their pre-existing beliefs about particular socioscientific issues. They recommend that students need to be provided with guidance in applying their NOS understandings during the decision-making process, and learn to critically evaluate scientific claims, some of which may oppose their pre-existing views. Research conducted by Bell and Lederman (2003) and Walker and Zeidler (2004) highlights the importance of providing guidance to enable learners to apply their views of NOS to their reasoning in socioscientific contexts.

Kolsto et al. (2006) also support the view that understandings of NOS are needed to allow students to engage with socioscientific issues. Lewis and Leach (2006) have highlighted the importance of providing explicit NOS instruction to enable students to effectively engage in socioscientific reasoning. They suggest that classroom instruction directed at developing students' argumentation skills, and moral and ethical reasoning abilities, would allow students to engage in socioscientific reasoning more effectively. Further studies are needed to examine the influence of these factors on learners' views of NOS and/or argumentation in socioscientific contexts.

Important trends that emerged from a consideration of the four studies conducted in scientific contexts showed that the two empirical studies that assessed participants' argumentation and views of NOS (Bell & Linn, 2000; Yerrick, 2000), reported improvements in both participants' argumentation and their views of NOS. Both of these studies implemented explicit or supported argumentation instruction that has previously been shown to aid in developing participants' skills and/or quality of argumentation in scientific contexts. Interestingly, although neither of these studies incorporated explicit NOS instruction, participants' views of NOS improved over the duration of the studies. On the basis of these findings a proposition could be forwarded that the integration of explicit NOS instruction may *not* be considered essential in scientific contexts where explicit argumentation instruction is provided. As this assertion is contrary to a large body of research in the field of NOS that supports the notion that explicit NOS instruction is necessary to aid in developing students' and teachers' views of NOS, one must exercise considerable caution in forwarding this claim. Thus, further research is needed to investigate this proposition.

The other two reviewed studies (Kenyon & Reiser, 2006; Sandoval & Millwood, 2005) did not directly assess participants' argumentative abilities or views of NOS. These studies were concerned with examining the influence of participants' views of NOS on scientific argumentation. Sandoval and Millwood (2005) suggested that students who display naïve views of NOS may not engage in scientific argumentation effectively, as they may not recognise the importance of providing explanations or warrants for their claims. Kenyon and Reiser (2006) suggested that students need to recognise the relevancy of epistemological ideas and their application to their decision-making. The results of their study indicate that the application of NOS ideas aided students' abilities to evaluate scientific arguments. Implications from the findings of these two studies suggest that a relationship exists between learners' views of NOS and their engagement (or lack of engagement) in scientific argumentation. Again, one must exercise caution in forwarding this claim as learners' views of NOS and skills and/or quality of argumentation were not directly assessed in either of these studies. Additional studies which provide an assessment of learners' NOS views and skills and/or quality of argumentation are needed to provide empirical evidence to lend support for this assertion.

Three important trends were highlighted from a review of the four empirical studies conducted in socioscientific contexts. First, results from the two studies (Zeidler et al., 2002; Walker & Zeidler, 2004) that assessed participants' argumentation skills and/or quality, indicated that participants' argumentation was poor, and did not improve over the duration of the studies. Neither of these studies implemented explicit argumentation instruction [although Walker & Zeidler (2004) did use a supported instructional approach], and the authors recommended that explicit argumentation instruction is necessary to aid in developing participants' skills and quality of argumentation. Second, only one of the reviewed studies (Walker & Zeidler, 2004) assessed the development of participants' views of NOS. Explicit NOS instruction was implemented in the study, and results indicated that participants' views of some aspects of NOS shifted to dynamic views of NOS. This finding is aligned with a significant body of NOS research that has shown the effectiveness of explicit approaches in developing participants' NOS views.

Third, a recommendation that stemmed from all of the reviewed studies focused on the importance of providing explicit NOS instruction in future studies. In particular, Bell and Lederman (2003), and Walker and Zeidler (2004), suggested that students require explicit instruction in using and applying their NOS understandings to socioscientific issues, as results from both of these studies reported that students' NOS views did not influence their reasoning or arguments. Conversely, Sadler et al. (2004) found that students' views of NOS did influence their reasoning and arguments, and Zeidler et al. (2002) found that participants' views of some aspects of NOS were reflected in their arguments. Thus, further research is needed to clarify this relationship.

A search of the research literature revealed one empirical study conducted in a historical context that examined NOS and argumentation (Ogunniyi, 2006). The study investigated the utilisation of argumentation as a reflective tool in developing valid views of NOS. Results indicated that teachers' views of NOS improved significantly from a naïve view of science to a dynamic view of science. The integration of explicit NOS and argumentation instruction was shown to aid in the development of participants' views of NOS in this study.

A consideration of the findings and trends identified in the reviewed studies highlight the importance of incorporating both explicit NOS instruction, and explicit argumentation instruction in studies that aim to develop learners' views of NOS. Learners need to recognise the relevancy of applying their understandings of NOS to their arguments to ensure that the arguments they develop are informed by epistemological considerations, and not narrowly focused on personal factors or pre-existing views. On the basis of these findings, the tentative claim could be made that integrating explicit NOS and argumentation instruction in the science classroom, and allowing learners to apply their views of NOS to their reasoning and arguments in scientific and/or socioscientific contexts, may lead to improvements in their views of NOS. This study will empirically test this claim.

4.7 Contribution of this research

A consideration of the broad literature base examined in this thesis informs the aims and design of this study. A review of NOS research outlined in Chapter 2 provided evidence to support the adoption of an explicit, contextualised approach to NOS instruction to aid in developing participants' views of NOS. Implementing this instruction within a science content course was recommended to allow contextualised NOS instruction to occur, and preservice primary teachers were chosen as ideal participants for the study as they have a pivotal role in providing NOS instruction to their students.

A review of argumentation research outlined in Chapter 3 provided evidence to support the adoption of an explicit argumentation instructional approach to aid in developing participants' skills and/or quality of argumentation. Engaging participants in argumentation in both scientific and socioscientific contexts was also recommended, as findings suggested that there may be a relationship between the context of argumentation, and the development of participants' skills and/or quality of argumentation.

A review of emerging research that has explored NOS and argumentation in this chapter provides evidence to support the inclusion of explicit NOS and argumentation instruction in scientific and socioscientific contexts, to aid in developing students' and teachers' views of NOS. Students also need to be provided with the opportunity to apply their views of NOS to their reasoning and arguments in scientific and/or socioscientific contexts. As only a small number of studies have been conducted in this area, further research is needed to substantiate these claims.

The aim of this study is to explore the influence of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS. The research questions guiding this exploratory study are:

1a. What are preservice primary teachers' initial views of the examined aspects of NOS?

1b. Do their views of these aspects of NOS change over the course of the intervention?

2. What is the influence of the various course components implemented during the study, on preservice primary teachers' views of the examined aspects of NOS?

3. What factors mediated the development of preservice primary teachers' views of the examined aspects of NOS?

This study will incorporate a classroom intervention that has been designed to include explicit, contextualised NOS instruction within a science content course. The course will utilise scientific and socioscientific contexts for argumentation, to provide opportunities for preservice primary teachers to apply their NOS understandings to their arguments. Explicit argumentation instruction will also be implemented throughout the classroom intervention. The following chapter will outline details of the research design developed to address the aim and research questions of this study.

CHAPTER 5 – RESEARCH DESIGN

5.1 Introduction

This chapter will provide a comprehensive overview of the research design developed to address the aim of this study:

> *The aim of this study is to explore the influence of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS.*

The purpose of this chapter is to provide a justification for the research design employed in this study. This chapter commences with an overview of the research orientation guiding this study, and critiques alternative methodologies that have been utilised in previous educational research. The basic tenets of the constructivist methodology that are adopted in this study will then be outlined, followed by a description of the research strategy employed in this study – case study research. Validity and ethical considerations will then be discussed, and a detailed description of the context of the study; including details of the participants, the researcher's role, and the course and its various components designed to aid in the development of participants' views of NOS will be outlined. The research procedure, including a description of the major phases of the intervention will follow, with a discussion of the various data sources utilised in this study, and an outline of how these data sources were analysed and interpreted. The chapter will conclude with a summary of the research design.

5.2 Research Orientation

Theoretical paradigms have been defined by scholars in various ways, for example, “a loose collection of logically held together assumptions, concepts, or propositions that orient thinking and research” (Bogden & Biklen, 1992, p. 33), and “a basic set of beliefs, a set of assumptions we are willing to make, which serve as touchstones in guiding our activities” (Guba & Lincoln, 1989, p. 80). Importantly, theoretical paradigms influence all aspects of a research study, and are also strongly influenced by researchers’ own worldviews and past experiences. In turn, a theoretical paradigm will influence the choice of research strategies to be employed in a study. Historically, two major paradigms have characterised the majority of research efforts in the field of education. The first of these paradigms is commonly termed ‘positivist’.

Historically, the dominant research approach in Western cultures has been represented by the basic beliefs of a paradigm that has been described as positivist, quantitative, conventional, or scientific. Guba and Lincoln (1989) outline that this paradigm is characterised by a realist ontology; a dualist, objectivist epistemology; and an interventionist methodology. As such the positivist paradigm assumes that “there exists a single reality that is independent of any observer’s interest in it and which operates according to immutable natural laws…” (p. 84). The researcher is viewed as a detached observer seeking to find out the ‘truth,’ and this perspective provides a decontextualised view of nature, with an aim to control and predict the phenomenon under investigation.

Research approaches have also been influenced by a paradigm that has been described as constructivist, qualitative, naturalistic, hermeneutic, interpretive, ethnographic or phenomenological. This paradigm is characterised by a relativist ontology that posits that realities are socially constructed and are not controlled by natural laws. This perspective views the 'truth' as an agreed upon consensus based on the most sophisticated and knowledgeable information currently available. The constructivist paradigm is characterised by a monoistic, subjectivist epistemology, and employs a naturalistic set of methodological procedures (Guba & Lincoln., 1989). Table 5.1 provides a summary of some of the main points of difference various authors (e.g., Bogden & Biklen, 1992; Denzin & Lincoln, 2000) have noted when examining the two paradigms. This research study aligns with the basic tenets of the constructivist paradigm, and the methodology employed in this study is detailed in the following section.

Table 5.1 *Major differences between the constructivist and positivist paradigms (adapted from Bogden & Biklen, 1992; Denzin & Lincoln, 2000)*

Constructivist paradigm	Positivist paradigm
Emphasis on the qualitative aspect of entities, and is primarily concerned with processes and meanings.	Emphasis on the quantitative aspect of entities, and is primarily concerned with experimental measurement and analysis of variables.
Emphasis on the value-laden nature of inquiry.	Emphasis on the value-free nature of inquiry.
Emphasis on the specifics of the phenomenon under investigation. Committed to an emic, idiographic, case-based position.	Emphasis on generalisations which can be drawn from investigating large numbers of random cases. Committed to a nomothetic or etic position.
Emphasis on understanding the relationships amongst aspects of the phenomena under investigation.	Emphasis on explanation and control of phenomena under investigation.

5.3 Constructivist Methodology

A constructivist research perspective is characterised by a number of distinct features, many of which are summarised below:

1. Constructivist researchers use a variety of methods to investigate an object or phenomenon, which allows more elaborate, in-depth understandings to take place. This perspective is not characterised by a particular assemblage of methods which are specific only to constructivist approaches.
2. Constructivist researchers emphasise the qualitative aspect of their data, rather than the quantitative aspect. Every-day events and their meanings are important to these researchers, as they are more concerned with processes, as opposed to products or outcomes.
3. Constructivist researchers utilise themselves as the key instrument in a study. An emphasis is placed on the natural setting as a vital source of data, and the behaviour of the researcher is acknowledged as exerting a significant effect on the environment in which the study takes place, and vice versa.
4. Constructivist researchers utilise a descriptive approach in reporting their data, as opposed to presenting their findings in numerical or statistical form. This approach allows the richness of dialogue to be expressed, and ensures that details which may appear to be trivial or insignificant, be considered as possible sources of data.

(Bogden & Biklen, 1992; Denzin & Lincoln, 2000; Erickson, 1998)

This study was guided by a constructivist research perspective that encompassed many of the above features. For example, the research took place in a natural setting as it was conducted within a preservice primary science content course, and employed the human instrument (the researcher) to implement all major phases of the study. A variety of qualitative methods such as questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts were utilised in the study to provide rich descriptions of the study's findings.

A theoretical framework influences the choice of research strategy to be employed in a study. Denzin and Lincoln (2000, p. 22) define a research strategy and/or design as "…a flexible set of guidelines that connect theoretical paradigms first to strategies of inquiry and second to methods for collecting empirical material." As a constructivist research perspective guided this study, a suitable research strategy which is aligned with the basic tenets of this perspective is case study research. This research strategy will be outlined in the following section.

5.4 Case study research

Case study research allows an in-depth investigation to take place within the real life context of participants, and allows a number of variables in a situation to be examined and presented as a single set of findings. Case studies can be approached from positivist and/or quantitative research orientations, or constructivist and/or qualitative research orientations. The case study approach outlined by Yin (1994) is closely aligned with a positivist and/or quantitative orientation, whereas Stake's (1995) approach to case study research is guided by a constructivist, qualitative orientation. As a constructivist methodology guides this study, the constructivist case study approach described by Stake (1995) will be adopted for this study. This approach is characterised by “researchers spending extended time, on site, personally in contact with activities and operations of the case, reflecting, revising meanings of what is going on” (Stake, 1998, p. 445).

This study will adopt an instrumental case study approach, where particular cases are investigated with an aim to provide information to help answer the research questions posed at the beginning of the study. The focus in an instrumental case study is not on a particular case, but on an understanding of the problem or issue to be investigated. Importantly, although the individual case is not of primary importance in instrumental case study research, it is imperative that each case is thoroughly and extensively examined, to provide the necessary information to help address the problem or issue being investigated. This study is also a collective case study as it examines a number of individual cases (Stake, 1998).

The selection of cases in instrumental case study research departs significantly from other research strategies that rely on sampling techniques such as random sampling. The primary criterion for the selection of cases in instrumental case study research is ‘the opportunity to maximise learning’ about the issue or problem to be investigated. As such, cases selected for investigation may be very similar or vastly different, depending on the issue examined. Researchers must very carefully choose their cases. Often this may mean that the most accessible cases are chosen for selection, simply because they allow the researcher to spend extended time with the cases, which in turn maximises the chances of learning about the issue or problem to be investigated (Stake, 1995).

This collective case study will examine five instrumental cases. The criteria used to select these cases was based on maximising opportunities to provide information to help address the research questions. As such, the five cases selected were the most accessible cases available, and the selection and details of these cases will be discussed in Section 5.6.1.

Case study research is a scientifically valid strategy that relies on numerous sources of evidence, and this methodological approach is characterised by rich, detailed, in-depth information about a small number of participants. As such, there are implications in attempting to present broad generalisations to other populations. Importantly, this strategy allows a comprehensive analysis of the specifics of a context to be explored in detail, thus this study will not attempt to draw broad generalisations from the results reported for five cases to larger populations. As Stake (1995, p. 8) points out “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 an emphasis on uniqueness…” The following section will outline and discuss the validity and ethical considerations that were taken into account in the study.

5.5 Validity and ethical considerations

Constructivist research is characterised by a continual search for new evidence, and a number of techniques have been identified to test out assertions and conclusions, and to allow the adequacy of a constructivist research study to be ascertained. The application of trustworthiness criteria (Guba & Lincoln, 1989), and methodological triangulation protocols (Denzin, 1984) were the techniques utilised in this study. The perspective and role of the researcher is also outlined in this section.

5.5.1 Trustworthiness criteria

The trustworthiness criteria consist of a set of four criteria that have been designed to correspond to conventional positivist criteria; namely, internal validity, external validity, reliability, and objectivity. As such, these criteria are often referred to as parallel criteria, and are termed - credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). The first of these criteria, credibility, corresponds to the conventional criterion, internal validity. Credibility seeks to verify the isomorphism between the "constructed realities of respondents and the reconstructions attributed to them" (Guba & Lincoln, 1989, p. 237). Three techniques were implemented to increase the credibility of this study.

The first of these techniques is prolonged engagement, which is achieved by engaging in a substantial involvement in the setting in which the study is based, to ensure a sense of rapport and trust is established with participants. This involvement allows the researcher to gain a greater appreciation of the culture of the context, and minimises any possible distortion of information from the study's participants. Prolonged engagement is achieved in this study by implementing the study intervention over a full university semester, with a small group of participants. The researcher conducted all major phases of the study, which included numerous interviews, discussions and observations of participants on a weekly basis. As such, rapport was well established, as contact with both the context site and its participants, was frequent and substantial.

Persistent observation augments prolonged engagement by ensuring that an adequate quantity of observations are taken to allow the researcher to identify the most relevant elements of the study, and to examine them in detail. As stated above, this study was conducted over an extended period, with regular, weekly observations of participants.

Peer debriefing has been described by Guba and Lincoln (1989, p. 237) as a "process of engaging, with a disinterested peer, in extended and extensive discussions of one's findings, conclusions, tentative analyses, and, occasionally, field stresses…" The researcher in this study took part in debriefing sessions with her research supervisor to clarify and develop emerging assertions, and to provide guidance with designing proceeding stages of the study.

This study also implemented negative case analysis during the data analysis phase of the study. Guba and Lincoln describe negative case analysis as:

> …the process of revising working hypotheses in the light of hindsight, with an eye towards developing and refining a given hypothesis (or set of them) until it accounts for all known cases. …the qualitative data analyst ought not to expect that 'all' cases would fit into appropriate categories. But when some reasonable number do, then negative case analysis provides confidence that the evaluator has tried and rejected all rival hypotheses save the appropriate one. (1989, p. 238)

The second trustworthiness criterion implemented in the study was transferability, designed to correspond to the conventional criterion, external validity. Transferability is "an empirical process for checking the degree of similarity between sending and receiving contexts" (Guba & Lincoln, 1989, p. 241). It relies on the technique of thick description (Geertz, 1973), and was attained in this study by thoroughly describing aspects of the study such as the context and site details (refer to Section 5.6 for a description of these aspects).

This thick description allows the reader to make their own transferability judgments about the study.

Dependability is the third trustworthiness criterion, corresponding to the conventional criterion, reliability. As such, dependability is associated with “the stability of the data over time” (Guba & Lincoln, 1989, p. 242). The nature of a constructivist study is such that shifts in constructions are a normal and expected aspect of the development of an emergent design. Importantly though, these shifts in constructions need to be able to be traced and documented to allow the process to be evaluated and judged by outside parties. This study incorporated a dependability audit to achieve this criterion, allowing the implementation of the study to be tracked and documented.

The final trustworthiness criterion, confirmability, corresponds to the conventional criterion, objectivity. Confirmability is “concerned with assuring that data, interpretations, and outcomes of inquiries are rooted in contexts and persons apart from the evaluator and are not simply figments of the evaluator’s imagination” (Guba & Lincoln, 1989, p. 243). As such, the constructions which emerged during this study are able to be traced back to their original sources. In this study, full transcripts of classroom discourse and interviews were kept to allow cross-checking to occur. The results sections of this thesis (refer to Chapters 6 & 7) incorporate verbatim quotes from participants’ transcripts, in addition to the researcher’s interpretations of this discourse.

5.5.2 Methodological triangulation

Triangulation, in its positivist sense can be defined as “the development of converging lines of inquiry” by utilising multiple sources of evidence (Yin, 1994, p. 92). These multiple data sources can be used to support, reject, or expand on the findings in question, and thus enhance the usefulness of a study. A constructivist perspective on triangulation views this process in a slightly different manner. Stake (1998, pp. 443-444) notes that “…no observations or interpretations are perfectly repeatable, (thus) triangulation serves also to clarify meaning by identifying different ways the phenomenon is being seen”.

This study employed methodological triangulation protocols (Denzin, 1984) to increase confidence in the validity of the study. Methodological triangulation involves utilising multiple methods and data sources, to maximise opportunities to identify possible influences on the issue under examination. This study utilised numerous data sources including interviews, audio- and video-taped classroom discourse, questionnaires and surveys, and written artefacts, to allow methodological triangulation to occur.

5.5.3 The perspective and role of the researcher

A constructivist perspective recognises that a researcher’s beliefs and ideologies influence all aspects of the research process, from the design of the research questions, through to the interpretations that are drawn from the analysis of data. As such, the researcher must ensure that any biases he or she holds are made explicit to the readers of the written study (Janesick, 1998).

It is also vitally important to describe the role of the researcher in the study, to enable readers of the study to understand the relationship between the researcher and the participants (Janesick, 1998). Constructivist researchers recognise that it is not possible to eliminate the influence of the researcher, and instead aim to understand and document this influence. It is particularly important to describe the role of the researcher in the present study as she designed and implemented all major phases of the study. She conducted all interviews with participants, and was the course lecturer in the classroom intervention phase of the study. She also marked and graded participants' assessment items in the course.

These factors all raise validity issues for the study, and many of these issues have been considered in Section 5.5.1. For example, peer debriefing was utilised in the study to ensure that the results and analyses of the study were clarified and viewed through multiple perspectives. This process enabled any biases in the reporting of the study to be identified and re-evaluated. Thick description was also used in the reporting of the study to allow the reader to make their own transferability judgments about the study. A dependability audit was incorporated that allowed the implementation of the study to be tracked and evaluated by outside parties. All interviews and classroom sessions were audio- and/or video-taped throughout the duration of the study. These tapes were made available to the researcher's supervisors, to allow them to check that the researcher 'did what she said she would do' in the study. Importantly, confirmability was established by ensuring that constructions emerging during the study were able to be traced back to their original sources. Classroom discourse and interviews were fully transcribed, and results of the study incorporated verbatim quotes from participants' transcripts, in addition to the researcher's interpretations of this discourse.

In addition, there is a recognition that the role of the researcher as 'data collector' presents some validity issues. Fontana and Frey (1998, p. 646) state "increasingly, qualitative researchers are realising that interviews are not neutral tools of data gathering but active interactions between two (or more) people leading to negotiated, contextually based results". This is an important point, although it should be stressed that the initial interview was conducted before the commencement of the main intervention, and the final interview was conducted after the assessment for the course had been marked and graded. These measures were taken to minimise the influence of the researcher's perspectives on the participants' interview discourse.

The researcher was the course lecturer during the study. At the time of the study she was a science education doctoral student who had previous experience in conducting research in the field of NOS. She was a qualified secondary science teacher, with a specialisation in chemistry. The researcher had acted as lecturer in the course over the past three years, and the administration of the course was overseen by one of the researcher's supervisors, a senior academic member of staff. Both of the researchers had previous research experience in the field of NOS.

The researcher's interest in NOS began during her B.Ed. (Hons) degree. During her first science methods lecture she was asked to describe her view of science and responded with a naïve perspective that focused on ‘science as an infallible body of knowledge’. When this view of science was challenged by her course lecturer, she began to recognise the limitations of viewing science in this manner. Over the duration of her science education studies her view of NOS developed to be aligned with more informed views. As a result of her interest in this area, she chose to investigate NOS for her honours thesis. This research examined four secondary science teachers’ views of NOS and their enacted classroom practice, and their students’ views of NOS (McDonald, 2000). She has also engaged in additional NOS research during her time as a doctoral student.

5.6 Context

This section provides details of the context of the study. The first sub-section outlines the participants of the study. Second, details about the science content course that provided the context for the main intervention of the study will be described. The final sub-section will provide a comprehensive overview of the course components implemented in the study that were designed to develop participants’ views of NOS.

5.6.1 Participants

This study was conducted with preservice primary teachers enrolled in a science content course conducted at a large urban university in Queensland, Australia. 17 preservice teachers were enrolled in the course, with the majority of these preservice teachers in their third year of a four year Bachelor of Education undergraduate degree. Preservice teachers entered the course having studied science (mainly biology and general science) to upper secondary levels with varying degrees of success. The majority of preservice teachers were in the age range 19-23 years and typically began their degrees immediately post-high school. Five of the teachers were mature age (i.e., between the ages of 30-50 years). The ethnic backgrounds of the teachers were similar with the majority of teachers of Caucasian descent, and the majority of the teachers were of middle class socio-economic status.

Access to participate in the study was sought from preservice teachers both verbally, and in written form. Initially, potential participants were identified from university enrolment data and the researcher contacted them individually via telephone to briefly explain the purpose of the study. Preservice teachers who expressed an interest in participating in the study were sent an information package outlining details of the purpose of the study, and general procedural aspects. They were informed that they would be video- and audio-taped during the majority of classroom sessions, and that they would be required to take part in interviews, and complete questionnaires throughout the study.

Preservice teachers were required to indicate their consent to participate in the study in writing, having read and understood the information package, and were also informed to outline any concerns they had with any aspects of the research. These requirements ensured informed consent was achieved. Potential participants were also assured that there were no extraordinary risks associated with the study, such as physical injury; they had the right to withdraw from the study at any time; and that the data obtained during the study would remain confidential. They were also informed that pseudonyms would be used in the reporting of findings to protect individual participants' identities, and that the study had been approved for implementation at both the faculty and university level. Ethical clearance had also been approved by the University ethics committee.

Sixteen preservice teachers enrolled in the course consented to participate in the study. Five of these 16 preservice teachers were selected for intensive investigation, and became case study participants in the study. Consistent with an instrumentalist case study approach (Stake, 1995, 1998), the criteria used to select these cases was based on maximising opportunities to provide information to help address the research questions (refer to Section 5.4 for more details). The five cases selected were the most accessible cases available, as these participants were regular class attendees, freely availed themselves for interviews and informal discussions, fully participated in all classroom activities, and completed all data collection task requirements in the course. As such, rich information was able to be obtained from these participants to aid in addressing the research questions guiding this study. It is important to note that although the remaining 11 preservice teachers completed the majority of the interviews, questionnaires, and classroom tasks implemented as possible sources of data in the study; all of these 11 participants failed to complete one or more of the data collection tasks implemented in the study. As such a complete data set was unable to be obtained from these preservice teachers.

The five case study participants represented a diverse range of academic ability levels, ages, life experiences, and gender; although it is important to note that the results reported in the study only apply to the case study participants, and no attempts should be made to generalise findings to the other course participants. Profiles of the case study participants will be provided in the following sub-sections.

5.6.1.1 Rachel

Rachel was a 19 year old, female preservice teacher in her 3rd year of study. She expressed that she had disliked science at high school, and had undertaken general science studies to year 12. Rachel had completed the core science content course required for her teaching degree in the previous year and was currently completing the core science methods course. She expressed a change in her view of science since high school, to something that she now enjoyed as a result of being able to organise and take charge of her own work. In her initial interview she expressed that she had not heard of NOS before, but had learnt about aspects of argumentation such as evidence and counterargument in high school social studies. Rachel was observed to be a quiet participant who tended not to dominate whole class discussions, or group discussions. She was also observed to be an industrious class member who appeared to put a lot of effort into classroom tasks. She achieved a grade of 5 (on a 7 point scale) for the course.

5.6.1.2 Monica

Monica was a 21 year old, female preservice teacher in her 3rd year of study. She expressed that she had enjoyed science at high school, and had undertaken biology in years 11 and 12, and general science studies in year 12. Monica had completed the core science content course required for her teaching degree in the previous year and was currently completing the core science methods course. In addition, she had also completed two science content elective courses during her teaching degree. In her initial interview, Monica expressed that she had not heard of NOS before, but had engaged in some argumentation activities in high school. She was observed to be an outgoing participant who was happy to participate in classroom activities and discussions, although she made no attempt to dominate these activities. She expressed an interest in science in general, and achieved a grade of 5 (on a 7 point scale) for the course.

5.6.1.3 Tom

Tom was a 30 year old, male preservice teacher in his 2nd year of study. He completed biology, chemistry and physics to senior level in secondary school. Tom held a Bachelor of Engineering degree which he completed in Edinburgh, and had previously worked as an engineer for eight years. He did not explicitly state why he no longer worked as an engineer, but had been working as a teacher aide for the past couple of years. He had previously completed the core science content and methods courses required for his degree, and expressed that he had enjoyed them. Tom was aiming to undertake all of the science electives offered in his degree to enable him to specialise in the teaching of science in primary schools.

In his initial interview, Tom expressed that he had previously learned about NOS and argumentation. He did not explicitly state where he had learned about NOS, but did state that he had learnt about argumentation in his tertiary studies, and during his teacher aide duties. Tom was observed as a confident participant who tended to dominate both group and whole class discussions, and was observed to use specialised scientific language in many of his oral contributions to class discussions. He achieved a grade of 6 (on a 7 point scale) for the course.

5.6.1.4 David

David was a 46 year old, male preservice teacher in his second year of study. He returned to secondary education and completed his senior school certificate after many years in the workforce. David did not offer any information about his previous work history. He commenced chemistry and biology during his secondary studies, but discontinued chemistry expressing that he was more interested in biology. He had completed the core science content course required for his teaching degree in the previous year, and was currently completing the core science methods course. He had also completed the biology science elective in his degree in the previous semester. In his initial interview, he expressed that he had not heard of NOS before, but was not explicitly asked if he had learnt about argumentation previously. David expressed that he enjoyed science, although he often referred to himself as a ‘slow learner’ with regard to learning scientific concepts. He was observed to be an outgoing participant and a major contributor to classroom discussions. David received a grade of 5 (on a 7 point scale) for the course.

5.6.1.5 Sarah

Sarah was a 20 year old, female honours preservice teacher in her 3rd year of study. She completed physics and biology to year 12, and had completed the core science content course required for her teaching degree in the previous year. Although Sarah expressed an interest in science in general, she had not enjoyed the core science content course expressing that the science content was not conceptually challenging. Sarah was currently completing the core science methods course, and was also completing the science electives offered in her degree. In her initial interview, she expressed that she had not heard of NOS, but had previously learnt about argumentation in high school English. Sarah was observed to be a quiet participant who tended not to dominate whole class discussions, but was a dominant member of her group discussions. She was observed to be a confident, industrious class member who achieved a grade of 6 (on a 7 point scale) for the course.

5.6.2 The science content course

'Natural and Processed Materials' is a single semester elective science content course which is typically undertaken by preservice primary teachers in their third year of university study, in a four year Bachelor of Education degree. Although the single semester course is an elective, it is one of a set of three science electives recommended for preservice primary teachers who wish to specialise in science teaching at the end of their degrees. As such, many of the preservice teachers who enrol in the course display an interest in science. Although the course does not stipulate any prerequisites, the majority of preservice teachers entering the course have completed a foundational science content course in their second year of study. Many preservice teachers also undertake a science methods course during the same semester.

The course teaches basic chemistry concepts and was designed with the underlying assumption that preservice teachers entering the course would generally possess limited conceptual knowledge of chemistry. The course is underpinned by a constructivist perspective whereby the teacher is viewed as a facilitator of learning. The learning environment is student-centred, with most classroom activities utilising group work, with an emphasis on collaborative learning. The science content of the course is concerned with the exploration of natural and processed materials in the environment. The course explores 11 scientific topics, namely: (1) properties of matter; (2) atoms and molecules; (3) chemical reactivity; (4) the electronic structure of atoms, and valency; (5) ions and ionic compounds; (6) the periodic table; (7) acids, alkalies and pH; (8) organic chemistry; (9) biological materials; (10) natural materials; and (11) synthetic materials. More information about the course topics is provided in Appendix A.

The course was taught by the researcher, who had previously taught and administered the course over the previous three years. The researcher is a qualified secondary science teacher with a specialisation in chemistry, and previous experience in the field of NOS (refer to Section 5.5.3 for more details). Classes were held weekly in three-hour sessions, and covered an 11-week teaching period. Each teaching session generally consisted of a theory section that addressed basic chemistry concepts, and an inquiry-based section that allowed participants to apply and develop their evolving conceptual knowledge.

In addition to these sections, six course components were implemented in the study to aid in the development of participants' NOS views. These course components were (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project. Explicit NOS and argumentation instruction was embedded during contextually relevant intervals, and participants were also engaged in various argumentation scenarios at contextually relevant intervals. The assessment for the course consisted of three items: (a) global warming task, (b) laboratory project, and (c) portfolio. The global warming task and the laboratory project were utilised as sources of data in the study as they provided important information pertaining to participants' NOS views. The portfolio was not used as a source of data in the study.

Participants also completed a superconductors survey during the study. The superconductors survey was also utilised as a source of data in the study as it provided important information pertaining to participants' NOS views. All six of these course components were specifically designed with the aim of developing participants' views of NOS, and will be discussed in more detail in the following section.

5.6.3 Course components designed to develop participants' views of NOS

Six course components were designed and implemented in the study to aid in the development of participants' views of NOS. These course components were (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project. It is important to note that some of these components have been utilised as assessment tools in previous studies [e.g., global warming task (Sadler et al., 2004), superconductors survey (Leach et al., 2000; Ryder & Leach, 2000)]. The rationale for their inclusion in this study was to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in scientific (superconductors survey) and socioscientific (global warming task) contexts, in addition to assessing their views of specific NOS aspects. As such, these components were utilised as both assessment *and* intervention tasks. The remaining four course components were intervention tasks that did not directly assess specific aspects of NOS.

5.6.3.1 Explicit NOS instruction

Aspects of NOS were explicitly taught (refer to Section 2.5.2 for details of an explicit NOS instructional approach) during classroom teaching sessions, with the following NOS aspects; (1) the empirical NOS, (2) the methods of science, (3) the functions and relationships of theories and laws, (4) the tentative NOS, (5) the inferential and theoretical NOS, (6) the subjective and theory-laden NOS, (7) the social and cultural NOS, and (8) the creative and imaginative NOS, being emphasised over the course of the main intervention. These NOS aspects were embedded within the science content of the course to enable contextualised NOS instruction to occur. This section will detail some episodes of planned explicit NOS instruction that took place during weekly class sessions. Importantly, many informal, unplanned opportunities for explicit NOS instruction also occurred during class sessions, due to the contextualised nature of the course.

During Week 1 of the main intervention, participants took part in a solubility practical activity which was designed to allow them to experience observing and theorising about solubility and the behaviour of substances. The distinction between observations and inferences was highlighted by the teacher during this activity. During a class discussion of why some groups had differing results, the lecturer highlighted the subjective and theory-laden NOS, and the social and cultural NOS, stressing that the results of experiments are subject to interpretation and are influenced by a scientist’s background and experiences.

Participants completed a practical activity exploring some of the principles of separation in Week 2. In a class discussion held at the end of the activity, the lecturer introduced the notion of the ‘scientific method,’ and highlighted that experiments did not necessarily follow a strict, stepwise procedure. Stimulus material was used as a springboard for a class discussion about the methods of scientific investigation. Participants were also introduced to the concepts of hypothesis, theory and law, and the lecturer highlighted the tentative NOS during this discussion. At the end of this teaching session, the lecturer provided a general introduction to the various aspects of NOS to be explored in the course. The purpose of this introduction was to enable participants to situate their developing understandings of the various aspects of NOS they will be introduced to during the course, into the wider context of the scientific enterprise.

Participants were also engaged in concept development about atoms and molecules during Week 2. General properties and structures of atoms, molecules, elements, and compounds were discussed in this session, and the lecturer introduced the history of atomic theory. The creative and imaginative NOS, and inferential and theoretical nature of atomic structure was highlighted in this session as the lecturer outlined that an atom is a model created by scientists to explain the behaviour of certain substances. Participants were provided with an overview of the various models of atoms developed over time, highlighting the tentative NOS, and the lecturer explained that each interpretation was an attempt to provide the best possible explanation of the theory based on the experimental evidence available at the time. In summary, the discussion of the history of atomic theory introduced and re-emphasised the notions of the tentative NOS, the creative and imaginative NOS, the inferential and theoretical NOS, and an understanding of scientific theories.

During Weeks 3 and 4, the aspects of NOS highlighted in the last session were re-emphasised and discussed. The empirical NOS was highlighted during discussions about argumentation in Weeks 4 and 5 that focused on the importance of supporting claims with scientific evidence.

The historical development of the periodic table was discussed in Week 6, during a concept development session about the periodic table. The lecturer discussed how there were gaps in the periodic table where Mendeleev hypothesised elements existed, but had yet to be discovered by scientists. When these elements were later discovered some of them fit with the original groupings, but others did not. Mendeleev had to change his original ideas about structuring the periodic table according to atomic mass, and structure it according to atomic number to accommodate these discrepancies. Aspects of NOS highlighted from this discussion included the nature of scientific laws, the difference between theories and laws, and the tentative NOS (the periodic table is still undergoing changes with the addition of new synthetic elements). The lecturer then discussed the discovery of new synthetic elements that are continually being added to the periodic table, and used the example of the American and Russian scientists who had both discovered and individually named element 104. This discussion highlighted the social and cultural NOS, and the subjective and theory-laden NOS.

During Week 7 the aspects of NOS highlighted in the last session were re-emphasised and discussed. Participants engaged in an oral presentation of the findings of their laboratory projects in Week 11. A class discussion followed where the lecturer highlighted that different groups can use the same information to plan and implement scientific investigations in very different ways. She also emphasised that results could be interpreted in a variety of ways, and utilised stimulus materials to further reinforce the subjective and theory-laden NOS, the social and cultural NOS, and the difference between observations and inferences.

5.6.3.2 Explicit argumentation instruction

Argumentation instruction was explicitly implemented (refer to Section 3.5.2 for details of an explicit argumentation instructional approach) during classroom teaching sessions by incorporating teaching materials developed from the Ideas, Evidence and Argument in Science Project 'IDEAS' (Osborne et al., 2004). These materials were specifically designed to support the teaching of ideas, evidence and argument in school science education, and placed a primary emphasis on the development of scientific reasoning. This section will detail episodes of explicit argumentation instruction that took place during weekly class sessions.

During Week 2 the lecturer introduced the concept of scientific argumentation, with a discussion of the importance of providing scientific evidence to support argumentation. This explicit argumentation instruction was a precursor to participants' engagement in the first scientific argumentation scenario, 'Mixtures, Elements, and Compounds' (refer to Section 5.6.3.3 for more details). During a class discussion that followed this scenario, the lecturer re-emphasised the importance of providing valid scientific evidence to support argumentation.

Participants were introduced to the definition of a scientific argument in Week 4. The teacher re-introduced the notion of providing valid scientific evidence to support argumentation by referring back to the ‘Mixtures, Elements, and Compounds’ argumentation scenario, and then discussed evaluating sources and quality of evidence. Examples of primary sources of data, such as peer-reviewed academic journals were contrasted with secondary or tertiary sources of data, such as popular culture magazines, and many internet sites and articles. The lecturer then introduced the notion of ‘What makes a good argument’ (Osborne et al., 2004b), and advised the participants that they need to be critical when evaluating evidence and its sources.

The participants were then introduced to the notion of ‘Argument prompts’ (Osborne et al., 2004b) utilised to aid in the construction of arguments. As a way of practicing argument construction, the participants engaged in a socioscientific argumentation scenario ‘Diet, exercise and cancer’ (refer to Section 5.6.3.3 for more details). Participants were required to develop arguments and counterarguments as they engaged in the scenario. A class discussion of this scenario took place in Week 5, and the importance of providing valid scientific evidence to support arguments, not simply personal opinions and unfounded statements was highlighted. The importance of critically analysing evidence was also re-enforced. The lecturer also discussed the importance of considering counterarguments, and highlighted the difference between counterclaims and counter-arguments. The notion of ‘qualifiers’ was also introduced and discussed.

The lecturer then introduced ‘Writing frames’ (Osborne et al., 2004b) to help participants structure their arguments more effectively. A second scientific argumentation scenario ‘Snowmen’ (refer to Section 5.6.3.3 for more details) was introduced to provide a context for participants to construct a written argument using writing frames to support one side of the argument, and counter the other side. During Week 7, the lecturer introduced Toulmin’s model of argument, and discussed the definitions of the various aspects of the model, including claims, data, warrants, qualifiers, backings and rebuttals. Participants were then introduced to a second socioscientific argumentation scenario ‘Cigarette smoking and cancer’ (refer to Section 5.6.3.3 for more details). This scenario provided an opportunity for participants to develop an argument to support or refute the claim ‘Cigarette smoking is associated with increased risk for various cancers and heart disease’. They were also asked to identify the data, warrants, qualifiers, backings, and rebuttals in their developed arguments. The lecturer also introduced the notion of ‘grounds’ of an argument, which entails incorporating the data, warrants and backings of an argument into a single aspect.

Participants engaged in a third socioscientific argumentation scenario ‘Foetal tissue transplantation’ (refer to Section 5.6.3.3 for more details) in Week 8. They were asked to develop an argument to support or refute the claim ‘Foetal tissue transplantation should be allowed to treat debilitating diseases’. In addition, they were asked to evaluate their arguments by utilising a framework created by

Osborne et al. (2004a) for evaluating arguments. The lecturer discussed the multi-level framework for evaluating the quality of arguments, and participants attempted to apply the framework to their arguments.

Importantly, argumentation instruction was implemented during classroom sessions without causing significant disruption to other classroom tasks. A contextualised instructional approach was utilised in the majority of instances whereby argumentation instruction was introduced at appropriate times to coincide with relevant scientific concepts discussed in the course. Details of the links between the science content of the course and the argumentation activities will be outlined in the following section.

5.6.3.3 Argumentation scenarios

Participants engaged in a set of five argumentation scenarios during the main intervention of the study. Two of these argumentation scenarios were situated in scientific contexts, and three of the scenarios were situated in socioscientific contexts (refer to Section 3.5.3 for details of scientific and socioscientific contexts for argumentation). Originally, a third scientific argumentation scenario was to be implemented in the course, but due to unforseen time constraints that arose during the implementation of the main intervention, this scenario was not incorporated in the class sessions. The rationale for the inclusion of the argumentation scenarios was to provide opportunities for participants to apply their evolving views of NOS, and understandings of argumentation, during the implementation of the scenarios.

5.6.3.3.1 Scientific argumentation scenarios

During the main intervention, participants engaged in two argumentation scenarios situated in scientific contexts. These scenarios were sourced from a set of curriculum materials (Osborne et al., 2004b) that were developed to support the teaching of ideas, evidence and argument in school science education. The scenarios were implemented in Weeks 2 and 5 of the main phase of the intervention, and were contextually linked to relevant scientific concepts addressed in the course. Group work was utilised during the implementation of each scenario to allow participants to express and defend their views, and a whole class discussion was held at the conclusion of the scenarios to further enable their views to be examined.

The first scientific argumentation scenario ‘Mixtures, Elements and Compounds’ was implemented in Week 2. The scenario investigates various scientific concepts related to elements, mixtures and compounds, and participants are required to provide evidence for a set of statements, and to construct arguments to justify their support for these statements. They are also encouraged to engage in counterarguments during this process. The implementation of this scenario coincided with the teaching of properties of matter during the classroom teaching session. Relevant aspects of NOS applicable to this scenario included the empirical NOS, and the subjective and theory-laden NOS. Full details of the scenario are provided in Appendix B.

The second argumentation scenario ‘Snowmen’ was implemented in Week 5. The aim of the scenario is to generate scientific argument and debate around competing theories of what will happen to two snowmen, one who is wearing a coat, and another who is not wearing a coat. Participants are asked to predict which snowman will melt first, on the basis of considering two alternative explanations that would support the melting of either snowman. They are provided with a list of evidence to evaluate, and asked to decide whether the evidence supports one theory, or the other, or both; and to provide justifications for their decisions. This scenario was linked to scientific concepts concerning heat transfer, and was directly related to the laboratory project (refer to Section 5.6.3.6 for more details). Participants were required to construct written arguments using writing frames to support one of the claims, and counter the other claim. They were provided with a page of scientific evidence to aid in the selection of appropriate data to support their arguments, and had to be critical in selecting appropriate evidence. Relevant aspects of NOS applicable to this scenario included the empirical NOS, subjective and theory-laden NOS, and creative and imaginative NOS. The full text of this scenario is provided in Appendix C.

5.6.3.3.2 Socioscientific argumentation scenarios

Participants engaged in three argumentation scenarios situated in socioscientific contexts during the main intervention. These scenarios were sourced from a set of four scenarios, and associated questions developed by Bell and Lederman (2003). The Decision Making Questionnaire ‘DMQ’ developed by Bell and Lederman was designed to obtain information about participants’ reasoning in a variety of socioscientific contexts, and has been previously implemented with university professors and research scientists. The full text of the item is provided in Appendix D.

The DMQ consists of four different socioscientific scenarios related to real-world issues, namely (a) foetal tissue transplantation, (b) global warming and greenhouse gas emissions, (c) diet, exercise, and cancer, and (d) cigarette smoking and cancer. Each written scenario was followed by a set of three to five questions designed to elicit the factors that influenced participants' reasoning. These questions were utilised to guide and structure group discussions, although it should be noted that the main focus of the task was utilising the scenarios to provide a platform for engaging participants in socioscientific argumentation.

Three scenarios were implemented in Weeks 4, 7 and 8 of the main phase of the intervention, and were contextually linked to relevant scientific concepts addressed in the course. Group work was utilised during the implementation of each scenario to allow participants to express and defend their views, and a whole class discussion was held at the conclusion of the scenarios to further enable their views to be examined.

The first socioscientific argumentation scenario 'Diet, exercise, and cancer' was implemented in Week 4. The scenario discusses the possible role of diet in initiating cancer, and the potential benefits of exercise in reducing the risk of cancer. This scenario was included to give participants the opportunity of practicing the construction of arguments, and was not contextually linked to any scientific content in the course. Participants were required to develop arguments and counterarguments in relation to this scenario.

The second argumentation scenario ‘Cigarette smoking and cancer’ was implemented in Week 7. The scenario provides evidence that supports a positive relationship between smoking and cancer, but also points out that smoking has not been ‘proven’ to cause cancer. Participants were required to develop arguments and counterarguments in relation to this scenario, and were also asked to try to identify the various components of argumentation utilised in Toulmin’s framework, within the socioscientific context. The implementation of this scenario coincided with the teaching of organic chemistry, with a focus on the organic compounds found in cigarettes.

The final socioscientific argumentation scenario ‘Foetal tissue transplantation’ was implemented in Week 8. The scenario is concerned with an experimental operation that utilises foetal tissue to treat Parkinson’s disease. A general overview of the experimental technique is outlined, followed by a fictional script about a daughter considering donating an unwanted foetus to her father, who is a sufferer of Parkinson’s disease. This socioscientific issue was introduced after a class discussion of biological, natural and synthetic materials, and was conceptually linked to a discussion of drugs and medicines. Participants were asked to develop arguments and counterarguments in relation to this scenario, and were also asked to evaluate the argument they created by utilising a framework created by Osborne et al. (2004a) for evaluating arguments.

Relevant aspects of NOS applicable to the three socioscientific scenarios included the empirical NOS, tentative NOS, subjective and theory-laden NOS, social and cultural NOS, and creative and imaginative NOS.

5.6.3.4 Global warming task

The global warming task was implemented in the study with the aim of aiding the development of participants' views of NOS. In addition, this task provided opportunities for participants to develop and apply their skills and/or quality of argumentation in a socioscientific context, apply their views of NOS to their reasoning about the task, and allow a comparison of participants' views of two specific NOS aspects in socioscientific contexts, to their views of these aspects of NOS in a decontextualised context. The global warming task consisted of two inter-related parts: (a) the global warming survey, and (b) the global warming essay.

The global warming survey was distributed to participants at the beginning of the main intervention. It consisted of a 'Science Brief' developed by Sadler et al. (2004) on the issue of global warming. The survey had previously been used to investigate high school students' views of NOS in response to a socioscientific issue. The scientific brief is presented in Appendix E and details a fictitious account based on the views of two groups of environmental scientists. Each group presents opposing views on the issue of global warming and outlines their views in a summary statement of their position. One group reports that global warming is an environmental threat caused by humans, and the other group states that global warming is a natural phenomenon that presents no threat to the environment. Both groups support their positions with scientific evidence, and the statements were designed to contain similar persuasive elements and identical amounts of data (some of the data provided in the statements were identical, but were interpreted in different ways by the scientists).

Participants were required to read both of the statements, and then respond to five open-ended questions that were designed to elicit their views of data use and interpretation, social and cultural influences on the development of scientific ideas, the subjective and theory-laden nature of scientific ideas, and the factors that influenced their reasoning on the issue. The five questions are outlined below (Sadler et al., 2004, p. 391):

1. Are data used to support either position? If so, describe the data and how they are used.
2. Do societal factors (issues not directly related to science) influence either position? If so, describe how these factors influence each argument? If not, describe why these factors would not influence each argument.
3. Why do the two articles, which are both written by scientists discussing the same material, have such different conclusions?
4. Which article is more convincing? Please explain your response.
5. Which article has more scientific merit? Please explain your response.

The survey was utilised as an introduction to the global warming essay. The essay was a major component of formal assessment in the course. After participants had received the science brief and read both position statements, they were then required to conduct research about global warming, and align themselves with one of the position statements. They were required to collect supporting evidence for their position, as well as providing counterarguments to rebut the position held by the other group of scientists. They were also required to include detailed information about the scientific principles of global warming, and the associated economic, social, political, and environmental impact of this phenomenon.

Participants presented their arguments in a seminar format during Weeks 9 and 10 of the main intervention and fellow participants were able to question and challenge their arguments during a classroom debate. They were required to critique the two position statements in their presentations by addressing the five open-ended questions cited above, and also to provide written responses to the guiding questions. Participants' global warming essays were submitted during the post-intervention phase of the study.

5.6.3.5 Superconductors survey

The superconductors survey was implemented in the study to provide opportunities for participants to apply their understandings of aspects of NOS to their reasoning in a scientific context. This survey also enabled an assessment of participants' views of the examined NOS aspects to be determined at the commencement and conclusion of the study, and findings from this assessment enabled changes in participants' views of the examined aspects of NOS to be ascertained. This survey also allowed a comparison of participants' views of NOS as expressed in the superconductors survey (scientific context), to their views of similar aspects of NOS expressed in the VNOS-C. Participants provided written responses to the survey during the pre- and post-intervention phases of the study, and also took part in follow up interviews to clarify and further probe their responses. The full text of the survey is provided in Appendix F.

The superconductors survey was sourced from a larger survey designed to investigate students' views about science. The survey was originally implemented in a comprehensive study that examined the role of labwork in science across several European countries (Leach et al., 2000). In the survey, participants are presented with a data interpretation context in which theoretical models have a central role. They must then demonstrate their understanding of the role of data and theoretical models in the interpretation of the data by responding to various questions (Ryder & Leach, 2000). The survey did not require that participants possess conceptual or technical knowledge of the topic, therefore allowing participants to make judgements about the models presented on the basis of the information contained in the survey alone.

The superconductors survey details a fictitious conference where scientists are investigating different models to explain the changes in the electrical resistance of a superconductor. Graphs are used to provide information about the electrical resistance of the superconductor at varying temperatures. Two groups of scientists are using different models to interpret the data presented. The first part of the survey requires participants to choose one of six statements related to the two proposed interpretations of the data presented. The second part of the item asks participants to rate a set of eight statements about what the next appropriate course of action is, and then choose the course of action they considered to be most important. The final part of the item requires participants to consider data about another superconductor, and to choose between four statements regarding their next course of action. Participants are also given the option during all parts of the item to add an alternative response if none of the provided responses align with their views.

5.6.3.6 Laboratory project

The laboratory project was implemented in the study to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in a scientific context, and also apply their understandings of NOS to their reasoning about the task. The project was a major component of formal assessment in the course, and participants were required to design and implement a laboratory project, and effectively report findings and draw conclusions. The laboratory project was an adaptation of a science fair project by Bochinski (1991), originally designed for middle and high school students, and is concerned with determining the most efficient substance for melting ice. In this study the original idea was modified and presented as a problem for participants to attempt to solve. The laboratory project was related to conceptual content introduced during the class session concerning heat transfer. Participants were provided with the following written scenario at the beginning of the main intervention:

> *The captain of a fishing trawler has approached your research group with a problem. He has a build-up of ice approximately 2 cm thick on the bottom of an aluminium ice box used to store fresh fish. He needs to be able to melt the build up of ice without damaging the aluminium. Your task is to determine what would be the most effective substance to carry out this process. You will need to consider factors such as speed, cost and efficiency in your recommendation.*

The following conditions are noted:

1. Outside air temperature is in the range of 18-25 degrees C.
2. No outside heat sources may be used (it is assumed there is no electricity available on the trawler).
3. No mechanical agitation of the ice is permitted (e.g., grinding, breaking up, agitating, etc.).
4. All groups will be provided with six aluminium baking pans and will have access to a very limited amount of freezer space.

Participants were required to work in groups to plan and conduct their experiments, and analyse their findings. They were also required to collect data, justify the use of their data, and deal with the ambiguity of their data during analysis. Groups carried out their laboratory projects over a four-week period from Week 7-10 of the main intervention. Each group then reported their findings in a class discussion held at the conclusion of the main intervention. The written laboratory projects were submitted during the post-intervention phase of the study.

Relevant aspects of NOS applicable to the project included the empirical NOS, methods of science, inferential and theoretical NOS, subjective and theory-laden NOS, social and cultural NOS, and creative and imaginative NOS. The following section will briefly outline the procedure of the study.

5.7 Procedure

The study was conducted in three phases. Each of these phases will be outlined in the following subsections. A summary of the research procedure is provided in Table 5.3.

5.7.1 Phase 1 - Pre-intervention

The pre-intervention phase of the study was conducted over a four-week period and involved the administration of an information package containing details of the study, consent forms, the VNOS-C questionnaire (refer to Section 5.8.1.1 for more details), and the superconductors survey, to preservice teachers enrolled in the course. This package was mailed to participants approximately four weeks prior to the commencement of classroom teaching sessions. Participants agreeing to take part in the study were requested to complete the two pre-intervention written items and return them to the researcher within a fortnight of receiving the package. Upon receipt of the returned information package, the researcher contacted individual participants to arrange an initial interview (refer to Section 5.8.2 for more details). These interviews were conducted over a two-week period.

5.7.2 Phase 2 - Main intervention

The main intervention of the study was conducted over an 11-week period, and implemented the classroom intervention phase of the study. Explicit NOS and argumentation instruction was embedded during contextually relevant intervals of the course, and participants were also engaged in various argumentation scenarios at contextually relevant intervals. Participants also took part in a global warming

Table 5.3 *Research procedure*

Research phase		Course topic	Argumentation scenarios	Explicit NOS instruction	Explicit argumentation instruction	Other course components	Other data sources
Pre-intervention (4 weeks)						Superconductors survey	VNOS-C Initial interview
Main intervention (11 weeks)	Week 1	1. Properties of matter		Subjective and theory-laden NOS, social and cultural NOS			
	Week 2	1. Properties of matter 2. Atoms and molecules	Scientific argumentation scenario 'Mixtures, Elements and Compounds'	Methods of science, theories and laws, tentative NOS, creative and imaginative NOS, inference and theoretical entities	General introduction to argumentation, importance of including evidence		
	Week 3	2. Atoms and molecules 3. Chemical reactivity		NOS aspects from Weeks 1 & 2 re-emphasised and discussed			
	Week 4	3. Chemical reactivity 4. The electronic structure of atoms and valency 5. Ions and ionic compounds	Socioscientific argumentation scenario 'Diet, exercise and cancer'	Empirical NOS	Evaluating evidence, general structure of a 'good' argument, argument prompts, counterarguments		
	Week 5	4. The electronic structure of atoms and valency 5. Ions and ionic compounds 6. Periodic table 7. Acids, bases and alkalies	Scientific argumentation scenario 'Snowmen'	Empirical NOS	Difference between counterarguments and counterclaims, qualifiers, writing frames, selecting relevant evidence		

Research phase		Course topic	Argumentation scenarios	Explicit NOS instruction	Explicit argumentation instruction	Other course components	Other data sources
	Week 6	6. Periodic table 7. Acids, bases and alkalies 8. Organic chemistry		Theories and laws, tentative NOS, subjective and theory-laden NOS, social and cultural NOS			
	Week 7	8. Organic chemistry	Socioscientific argumentation scenario 'Cigarette smoking and cancer'	NOS aspects from Weeks 4-6 re-emphasised and discussed	Toulmin's model of argumentation (general structure and definitions of components), grounds of argument	Laboratory project	
	Week 8	9. Biological materials 10. Natural materials 11. Synthetic materials	Socioscientific argumentation scenario 'Foetal tissue transplantation'		Evaluating the quality of argumentation	Laboratory project	
	Week 9					Laboratory project Global warming survey	
	Week 10					Laboratory project Global warming survey	
	Week 11			Subjective and theory-laden NOS, social and cultural NOS		Laboratory project (oral discussion)	
Post-intervention (3 weeks)						Global warming essay Superconductors survey	VNOS-C Final interview

task, and laboratory project during this phase of the study. Details of these course components were outlined in Section 5.6.3.

5.7.3 Phase 3 - Post-intervention

The post-intervention phase of the study was conducted over a three-week period and involved the administration of the VNOS-C questionnaire and the superconductors survey. Participants completed the NOS questionnaire during the final classroom teaching session, and were given the superconductors survey to complete at home. They also took part in a final interview (refer to Section 5.8.2 for more details), and these individual interviews were scheduled and conducted 2-3 weeks after the conclusion of the main intervention. Submissions of the global warming essay and written laboratory project also occurred in the post-intervention phase of the study. The following section will outline the data sources utilised in this study.

5.8 Data Sources

This section will discuss the primary sources of data that provided evidence for the interpretations, recommendations and implications that emerged during the course of this study. Four sources of data were utilised in this study: questionnaires and surveys; interviews; audio- and video-taped class sessions, and written artefacts. Each of these data sources will be discussed in the following subsections.

5.8.1 Questionnaires and surveys

5.8.1.1 VNOS-C

The Views of Nature of Science Questionnaire ‘VNOS-C’ and associated semi-structured interviews were utilised to assess participants’ pre- and post-intervention NOS views. The VNOS-C (refer to Appendix G for the full text of the item) was developed by Abd-El-Khalick (1998), and the rationale behind the development of this open-ended instrument was to avoid many of the methodological problems experienced when utilising standardised, forced-choice instruments that have historically been used in NOS studies (refer to Section 2.7 for more details). The VNOS-C has been previously used to assess preservice elementary teachers’ (Abd-El-Khalick & Lederman, 2000b); preservice and inservice secondary science teachers’ (Abd-El-Khalick et al., 1998; Lederman et al., 1999; Schwartz & Lederman, 2002); and undergraduate and graduate college students’ (Abd-El-Khalick, 1998) views of NOS.

The VNOS-C utilises both contextualised and decontextualised questions to assess participants’ views of the empirical NOS, the methods of science, the functions and relationships of theories and laws, the tentative NOS, the inferential and theoretical NOS, the subjective and theory-laden NOS, the social and cultural NOS, and the creative and imaginative NOS. Abd-El-Khalick (1998) also developed an interview schedule that may be used to aid in clarifying and further probing respondents’ written responses to the VNOS-C.

Follow up interviews have previously been used with earlier versions of VNOS to ensure participants’ responses were not misinterpreted. These interviews were utilised to authenticate the interpretations generated by the interviewer, and allowed the face validity of the instrument to be established. The construct validity of the questionnaire has been established in previous studies (Bell, 1999) by comparing NOS profiles generated from separate analyses of data from the VNOS questionnaires, and their corresponding interview transcripts, indicating that participants' NOS views were indeed comparable across both sources of evidence.

Participants in this study were administered the VNOS-C during the pre-intervention and post-intervention phases of the study, with follow up interviews also being conducted at these times. The VNOS-C took approximately 30-45 minutes to complete. Participants were reminded that there were no 'correct' answers to the questions, and were reassured that the aim of the questionnaire was to find out their views about some aspects of NOS, not test their science conceptual knowledge. After the administration of the written questionnaire, the participants were individually interviewed to clarify their responses to the questionnaire items. Participants were given a copy of their questionnaire responses and asked to read out their answers to each of the VNOS-C questions. They were then asked to further explain and elaborate on their responses. The interview schedule developed by Abd-El-Khalick (1998) was often utilised to clarify any ambiguities present in their written responses and also probe and explore relevant meanings and findings. The follow up interviews took approximately 30 minutes to complete, and all interviews were audio-taped and fully transcribed for analysis.

5.8.1.2 Global warming survey

The global warming survey was utilised during the main intervention phase of this study to provide opportunities for participants to apply their understandings of specific aspects of NOS to their reasoning in a socioscientific context, and to allow a comparison of participants' views of two specific NOS aspects in socioscientific contexts, to their views of these aspects of NOS in a decontextualised context. Details of the global warming survey were provided in Section 5.6.3.4. Participants presented their oral responses to the global warming survey during Weeks 9 and 10 of the main intervention.

5.8.1.3 Superconductors survey

The superconductors survey was implemented in the study to provide opportunities for participants to apply their understandings of aspects of NOS to their reasoning in a scientific context. This survey also enabled an assessment of participants' views of the examined NOS aspects to be determined at the commencement and conclusion of the study, and findings from this assessment enabled changes in participants' views of the examined aspects of NOS to be ascertained. This survey also allowed a comparison of participants' views of NOS as expressed in the superconductors survey (scientific context), to their views of similar aspects of NOS expressed in the VNOS-C. Details of the superconductors survey were provided in Section 5.6.3.5.

5.8.2 Interviews

Participants took part in an initial and final interview. The initial interview was conducted during the pre-intervention phase of the study, and background information was sought from participants regarding their previous science education and experience, their feelings about science, any previous exposure to NOS or argumentation instruction, and general demographical information (e.g., age, socioeconomic background, gender, etc.). Participants were also interviewed about their responses to the pre-intervention VNOS-C, and the pre-intervention superconductors survey during the initial interview. These data sources were discussed in the previous section.

During the post-intervention phase of the study, participants took part in a final interview designed to provide an overview of the learning that occurred throughout the course. The final interview was semi-structured, and consisted of 16 questions designed to provide information about participants' perceptions of the course including: whether they felt they had learnt about NOS and argumentation, whether they found learning about NOS and argumentation useful, whether they could refer to specific instances in the course where they learnt about NOS and argumentation, and whether they could provide a definition or explanation of NOS or argumentation. The full text of the item is provided in Appendix H.

Participants were also interviewed about their responses to the post-intervention VNOS-C, and the post-intervention superconductors survey during the final interview. These data sources were discussed in the previous section. Initial and final interviews were audio-taped and fully transcribed for analysis.

5.8.3 Audio- and video-taped class sessions

Weekly classroom teaching sessions conducted during the main intervention were audio- and/or video-taped to provide information about the relevant impact of many of the course components designed to aid the development of participants' views of NOS. Participants' engagement in explicit NOS instruction, explicit argumentation instruction, the argumentation scenarios, and the oral presentation of the global warming survey were audio- and/or video-taped, and resulting discourse fully transcribed for analysis. Details of the course components were provided in Section 5.6.3.

5.8.4 Written artefacts

Two written artefacts were examined in this study, the global warming essay, and written laboratory project. The global warming essay was implemented in the study to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in a socioscientific context, and also apply their understandings of NOS to their reasoning about the task. Details of the global warming essay were provided in Section 5.6.3.4.

The laboratory project was implemented in the study to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in a scientific context, and also apply their understandings of NOS to their reasoning about the task. Details of the laboratory project were provided in Section 5.6.3.6.

Participants' global warming essays and written laboratory projects were submitted during the post-intervention phase of the study. The following section will outline the methods of data analysis used to examine and interpret the data sources.

5.9 Data analysis and interpretation

This section will provide an overview of the data analysis and interpretive methods utilised in this study. Four sources of data provided evidence for the resultant analysis and interpretation, namely - questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts. Data analysis was conducted at the conclusion of the study and involved the formation of various assertions that informed the major findings of the study. A variety of validity and ethical protocols were considered during the analysis to ensure the findings and interpretations emerging from the data were valid. These protocols included implementing trustworthiness criteria, applying methodological triangulation techniques, and considering the perspective and role of the researcher during data analysis. These protocols were discussed in Section 5.5.

5.9.1 Questionnaires and surveys

5.9.1.1 VNOS-C

The first stage of analysing the VNOS-C involved generating separate NOS profiles from each participant's questionnaire and interview data, and comparing these two data sources to ensure the views expressed in each source were comparable. This initial analysis indicated that the two sources were indeed comparable, and a single NOS profile was developed for each participant.

Many previous studies that have implemented the VNOS-C have coded participants' responses to the questionnaire as either naïve or informed. Initial data analysis uncovered some difficulties in coding participants' responses into two distinct categories, as many of the responses indicated intermediate positions.

An underlying assumption that guided this study recognised that participants' views of NOS were unlikely to be fundamentally shifted from naïve to informed over the relatively short duration of this study. Four categories of response were developed in this study to enable a detailed, differential classification of participants' views of the examined NOS aspects. These categories were modified from the original descriptions and elaborations of each NOS aspect developed by Abd-El-Khalick (1998). It is important to note that other researchers (e.g., Abd-El-Khalick and Akerson, 2004) have utilised similar terms for coding participants' NOS views with subtle differences in emphasis.

Participants' views of the examined aspects of NOS in this study were coded on a continuum, as either naïve, limited, partially informed, or informed. The developmental progression of these aspects can be illustrated as follows:

Naïve → Limited → Partially informed → Informed

Less desirable understandings → *More desirable understandings*

In this study, participants' views of a particular NOS aspect coded as partially informed or informed represented desired understandings of the aspect. Naïve or limited views of a particular NOS aspect represented undesirable understandings of the aspect, in need of improvement.

Full details of the coding for each of the examined NOS aspects are provided in Appendix I. A sample of the data generated from the VNOS-C was also coded by a professor of science education who had previous experience in NOS research, to assess the reliability of the coding scheme. After discussions of the generated codes, consensus was reached. An example of the coding rubric developed for one of the examined NOS aspects (creative and imaginative NOS) is outlined in Table 5.4.

Table 5.4 *Coding rubric for 'Creative and imaginative' NOS aspect (adapted from Abd-El-Khalick, 1998)*

Naïve view	Limited view	Partially informed view	Informed view
Scientists do not use creativity and imagination in their investigations. Science is a lifeless, rational, and orderly activity based solely on empirical evidence.	Scientists use creativity and imagination but such use is not desirable. Creativity and imagination are often used to bias or "distort" investigations in order to fit scientists' agendas to publish and/or secure funding. May or may not provide examples or provides examples derived from everyday life situations. Scientists only use creativity and imagination in the planning and design stages. Using imagination and creativity in data collection, data interpretation or in deriving conclusions would result in "incorrect" findings. Conclusions should be based solely on the data.	Creativity and imagination are needed in all stages of scientific investigation, but may not use the term "creativity and imagination" to refer to the 'invention' of explanations, models or theoretical entities. Rather used the terms to refer to "resourcefulness, skilfulness, or cleverness. " May equate creativity and imagination with being open-minded, considering all the possibilities, and examining a situation from "all the angles." These views may be implicit. No explicit use of 'invention.' Provides adequate examples derived from science or scientific practice. Scientists use creativity and imagination in all stages of investigation with the exclusion of data collection.	Imagination and creativity are need in scientific investigation and permeate all stages of scientific investigation. Use of the term "creativity and imagination" refers to the 'invention' of explanations, models or theoretical entities. Provides appropriate examples derived from science or scientific practice. Recognises the empirical NOS but nonetheless the development of scientific knowledge involves human imagination and creativity. Science involves the invention of explanations and theoretical entities. Creativity influences the interpretation of data.

Eight broad aspects of NOS were assessed in this study, with some aspects comprising one or more sub-aspects. These assessed NOS aspects were:

1. Empirical NOS,
2. Methods of science (comprising scientific method, aim and general structure of experiments, idea of outcome, and validity of observationally based disciplines),

3. Theories and laws (comprising explanatory function of theories, well-supported nature of theories, difference and relationship between theories and laws, and ranking of theories and laws),
4. Tentative NOS,
5. Inference and theoretical entities (atoms and species),
6. Subjective and theory-laden NOS,
7. Social and cultural NOS, and
8. Creative and imaginative NOS.

Participants' responses to the VNOS-C questionnaire and follow-up interview were coded under each of these eight aspects of NOS at both the pre-intervention and post-intervention phases of the study. Participants' NOS profiles generated at these stages were then able to be compared to allow an assessment of the possible development of their NOS views over the duration of the intervention.

5.9.1.2 Global warming survey

The global warming survey consisted of five open-ended questions designed to elicit participants' views of data use and interpretation, social and cultural influences on the development of scientific ideas, the subjective and theory-laden nature of scientific ideas, and the factors that influenced their reasoning on the issue. The five questions were outlined in Section 5.6.3.4. Two of the five questions on the survey were selected for data analysis as they provided information about participants' views of the social and cultural NOS (Question 2), and the subjective and theory-laden NOS (Question 3). As these aspects of NOS were part of the set of eight aspects chosen for examination in this study (as assessed by the VNOS-C), information obtained from participants' responses to these items enabled a comparison of their views of these aspects of NOS in the global warming survey (socioscientific context) to their views of these aspects of NOS as expressed in the VNOS-C.

Participants presented their responses to the survey questions in a seminar format during Weeks 9 and 10 of the main intervention. Their oral discourse was video-recorded and fully transcribed for analysis. Participants' views of the two examined aspects of NOS were coded on a continuum, as either naïve, limited, partially informed, or informed; utilising the same coding scheme developed to analyse participants' VNOS-C responses (refer to Section 5.9.1.1 for more details). This first stage of data analysis enabled an assessment of participants' views of the social and cultural NOS, and the subjective and theory-laden NOS, as expressed in the global warming survey, to be ascertained. The second stage of data analysis involved comparing participants' views of these aspects of NOS, to their views of the same aspects of NOS, as expressed in the VNOS-C.

5.9.1.3 Superconductors survey

Initial data analysis involved comparing participants' written responses to the survey questions, to their oral responses expressed in the follow up interviews. Previous studies that have utilised this survey (Leach et al., 2000; Ryder & Leach, 2000) found that participants' written responses often did not correlate with their oral responses, and many written responses that would have been coded as 'relativist' or 'model-focused' were indeed found to be more closely aligned with 'data-focused' responses. The authors concluded that follow up interviews were an important component of assessing participants' views of NOS in this context.

In this study, transcripts of discourse from the follow up interviews were compared with participants' written responses, and where discrepancies arose between the two data sources, the interview data was taken to be the more accurate interpretation of the participants' position. Data analysis in this study revealed that discrepancies between written and oral responses were uncommon, although they did occasionally occur. A profile of participants' expressed views of NOS in response to the superconductors survey was generated at both the pre-intervention and post-intervention phases of the study.

Following the coding scheme developed by Ryder and Leach (2000), participants' responses to each of the three sections of the survey were coded as either 'data focused views,' 'model focused views,' or 'relativist focused views.' In this study, participants who exhibited predominantly data focused views across the three sections of the survey represented less desirable understandings of NOS. Conversely, participants who exhibited predominantly model focused or relativist focused views across the three sections of the survey represented more desirable understandings of NOS.

Predominantly data focused views	Predominantly model focused or relativist focused views
↓	↓
Less desirable understandings	*More desirable understandings*

Descriptions of each of these views of NOS are provided in Table 5.5.

Table 5.5 *Descriptions of epistemological views (Ryder & Leach, 2000; Leach et al., 2000)*

Data focused views	Model focused views	Relativist focused views
Data focused views reflect a belief in the primacy of data. The processes of measurement and data collection are viewed as simply involving ‘copying’ from reality, and the process of drawing conclusions is a simple one of stating what happened in an experiment. Scientific knowledge claims are viewed as descriptions of the material world, and differences of interpretation can be resolved by collecting enough data of an appropriate form.	Model focused views recognise the importance of considering underlying models when interpreting data. Understands the distinction between models, predictions and data. Recognition that data treatment should be informed by underlying models, and that models are based on theoretical ideas and data collected through experimental measurements.	Relativist focused views reflect the view that there are limited grounds for assessing the truth of knowledge claims in science. Multiple interpretations of the same data are possible. Data interpretation is subjective and theory-laden, is influenced by factors such as a scientists’ theoretical orientations, beliefs, previous knowledge, experiences and expectations. Appreciates the role of data as providing empirical evidence to support the chosen position.

Full details of the coding scheme are provided in Appendix J. A sample of the data generated from the VNOS-C was also coded by a professor of science education who had previous experience in NOS research, to assess the reliability of the coding scheme. After discussions of the generated codes, consensus was reached. Coded responses to each of the three sections of the survey were amalgamated to provide an assessment of each participants overall view of NOS. A comparison of participant’s pre- and post-intervention views of the examined aspects of NOS enabled an assessment of the development (or lack thereof) of participants’ views of the examined NOS aspects over the duration of the study.

Participants’ views of the examined NOS aspects as assessed by the superconductors survey were then compared to their views of similar aspects of NOS as assessed on the VNOS-C. The empirical NOS and the subjective and theory-laden NOS were identified as similar aspects of NOS across both instruments, and participants’ views of NOS as assessed by the superconductors survey were compared to their views of the empirical NOS, and the subjective and theory-laden NOS as assessed by the VNOS-C. It is important to note that the use of different coding schemes across these two instruments limits a direct comparison of views of NOS, although it does allow an assessment of general trends in NOS views across contexts.

5.9.2 Interviews

Participants' responses to the initial and final interview questions were fully transcribed for analysis. These transcripts provided evidence of participants' self perceptions of the course, and provided important information regarding perceived changes in their views, and the attributions for these changes. This information was utilised to aid in assessing the impact of the various course components on participants' views of NOS.

Participants were also interviewed about their responses to the pre-intervention VNOS-C, and the pre-intervention superconductors survey during the initial interview. These data sources were discussed in Sections 5.9.1.1 and 5.9.1.3.

5.9.3 Audio- and video-taped class sessions

Audio- and video-recordings of weekly classroom teaching sessions conducted during the main intervention were fully transcribed for analysis. These transcripts provided information about the relevant impact of many of the course components designed to aid the development of participants' views of NOS. Transcripts were searched for explicit references to NOS, and compared to participants' views of NOS as assessed by the VNOS-C.

5.9.4 Written artefacts

Participants' global warming essays and written laboratory projects were searched for explicit references to the examined NOS aspects, and any identified aspects were highlighted and compared to participants' views of NOS as assessed by the VNOS-C.

5.10 Summary

The purpose of this chapter was to provide a justification for the research design employed in this study. This study aligns with the basic tenets of the constructivist paradigm and is characterised by a monoistic, subjectivist epistemology, and employs a naturalistic set of methodological procedures (Guba & Lincoln., 1989). As a constructivist research perspective guided this study, a suitable research strategy aligned with the basic tenets of this perspective was employed. This research strategy was case study research. Case study research allows an in-depth investigation to take place within the real life context of participants, and allows a number of variables in a situation to be examined and presented as a single set of findings. This study adopted an instrumental case study approach, where particular cases were investigated with an aim to provide information to help answer the research questions posed at the beginning of the study. The study is also a collective case study as it examines five individual cases.

Constructivist research is characterised by a continual search for new evidence, and a number of techniques have been identified to test out assertions and conclusions, and to allow the adequacy of a constructivist research study to be ascertained. This study applied trustworthiness criteria (Guba & Lincoln, 1989), and methodological triangulation protocols (Denzin, 1984); and also considered the perspective and role of the researcher, to ensure the study's findings and interpretations were valid.

This study was conducted with preservice primary teachers enrolled in a science content course conducted at a large urban university in Queensland, Australia. Sixteen preservice teachers enrolled in the course consented to participate in the study, and five of these preservice teachers were selected for intensive investigation, and became case study participants in the study. The science content course is a single semester elective course, and is one of a set of three science electives recommended for preservice primary teachers who wish to specialise in science teaching at the end of their degrees. Classes were held weekly in three-hour sessions, and covered an 11-week teaching period. Six course components were designed and implemented in the study to aid in the development of participants' views of NOS. These course components were (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project.

The study was conducted in three phases. The pre-intervention phase of the study was conducted over a four-week period, and incorporated the administration of the VNOS-C questionnaire and superconductors survey, and the initial interview. The main intervention phase of the study was conducted over an 11-week period, and implemented the classroom intervention phase of the study. The post-intervention phase of the study was conducted over a three-week period and involved the administration of the VNOS-C questionnaire and superconductors survey, and the final interview.

Four primary sources of data were used to provide evidence for the interpretations, recommendations and implications that emerged during the course of the study. The data sources included questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts. Data analysis was conducted at the conclusion of the study, and involved the formation of various assertions that informed the major findings of the study. A variety of validity and ethical protocols were considered during the analysis to ensure the findings and interpretations emerging from the data were valid.

The following chapter will address the first research question by providing a comprehensive assessment of participants' pre- and post-intervention views of the examined aspects of NOS.

CHAPTER 6 – RESULTS – VIEWS OF NOS

6.1 Introduction

This chapter will provide a comprehensive assessment of participants' pre- and post-intervention views of the examined aspects of NOS. Findings from this assessment will provide evidence to address the first research question:

1a. *What are preservice primary teachers' initial views of the examined aspects of NOS?*

1b. *Do their views of these aspects of NOS change over the course of the intervention?*

The purpose of this chapter is to explore the change (or lack thereof) in participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. The following section of this chapter details participants' pre-intervention views of NOS, as assessed by the VNOS-C. This section is proceeded by an overview of participants' post-intervention views of NOS, including an assessment of the development (or lack thereof) of these views, as assessed by the VNOS-C. A summary of participants' NOS views will then be detailed, followed by an analysis and comparison of participants' VNOS-C profiles, and final interview transcripts pertaining to NOS. Three important trends in the data will be identified, followed by a summary of the chapter.

6.2 Pre-intervention views of NOS

Participants' responses to the VNOS-C questionnaire, and follow up interviews administered at the commencement of the study will be presented and analysed in this section. Participants' views of each of the eight examined NOS aspects will be discussed in separate sub-sections. A summary statement (adapted from Abd-El-Khalick, 1998, 2001) representing an informed view of each examined NOS aspect will be provided at the beginning of each sub-section. Full details of the coding rubrics for each of the examined NOS aspects are provided in Appendix I. Segments of transcript will be utilised to provide support for the assessments provided by the researcher. A summary of individual participants' views of each of the examined NOS aspects is provided in Table 6.1.

6.2.1 Empirical NOS

Scientific knowledge is empirically based and is generally derived from observations of natural phenomena, and these observations are always influenced by human assumptions and previous knowledge (and are thus theory-laden). Science involves the formulation of ideas (e.g., hypotheses, theories). Evidence is then sought to either support or discount these ideas, which is different from religion. Regarding the term 'empirical', participants expressing an informed view of this aspect of NOS do not indicate that tangible data can be used to 'prove' scientific claims or that science is based on observations of phenomena to the exclusion of other personal, social or cultural attributes. Even though science relies on evidence and observation, there is much in science that is based on belief, convention, and the non-observable (Abd-El-Khalick, 2001, pp. 13-15).

Four of the five participants (Monica, Tom, David, and Sarah) expressed limited views of the empirical NOS. Although these participants recognised that scientific knowledge relies on evidence, many of them failed to recognise that

Table 6.1 *Summary of participants' NOS views*

	Rachel			**Monica**			**Tom**			**David**			**Sarah**		
NOS Aspect	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
Empirical	+	++	D	-	+	D	-	+	D	-	-	U	-	-	U
Methods of science	-	+	D	-	+	D	-	+	D	--	-	D	--	-	D
Theories and laws	-	-	U	-	-	U	-	-	U	-	-	U	-	+	D
Tentative	+	+	U	-	++	SD	+	+	U	-	-	U	-	-	U
Inference and theoretical entities	-	+	D	--	-	D	+	+	U	--	--	U	+	++	D
Subjective and theory-laden	-	++	SD	+	++	D	-	+	D	-	-	U	-	+	D
Social and cultural	-	++	D	+	+	U	-	+	D	-	-	U	-	+	D
Creative and imaginative	-	+	D	-	+	D	-	+	D	-	-	U	+	+	U
TOTAL + or ++	**2**	**7**		**2**	**6**		**2**	**7**		**0**	**0**		**2**	**5**	
TOTAL D or SD			**6**			**6**			**5**			**1**			**5**

(--) Naïve view of NOS aspect
(-) Limited view of NOS aspect
(+) Partially informed view of NOS aspect
(++) Informed view of NOS aspect
(U) View of NOS aspect largely unchanged
(D) View of NOS aspect developed
(SD) View of NOS aspect significantly developed

scientific knowledge is influenced by human assumptions and previous knowledge. For example, Sarah emphasised that science is more concrete and absolute than religion:

> I think science is something that is testable and you can experiment and find a definite answer to it or at least get a few results whereas religion is all…it's very subjective, it's kind of a human experience of how you debate it that way. (Sarah, VNOS, Q1).

References to science being concrete and absolute were also noted by Tom and David. The use of the term 'prove' was noted by a number of participants. For example, David's view of science implied that tangible evidence can be used to 'prove' scientific claims:

> Science is a study of the real things which affect our lives on this planet. These things can be proven and are not subject to opinions or emotional input. (David, VNOS, Q1)

Monica also indicated that science is able to 'prove' things, and when asked to clarify her use of the term, she stated "Prove that it's true or it happens…" (VNOS, Q1), thus subscribing to the limited view that empirical evidence has the sole role in the development of scientific knowledge, and that scientific 'truths' are developed by using empirical data alone.

Rachel was the only participant who expressed partially informed views of the empirical NOS. She recognised the importance of observable evidence in science, but did not indicate in her response that scientific knowledge is solely based on empirical evidence, nor did she indicate that scientific knowledge is absolute, concrete, or proven true:

> Science is the study of the physical world for the purpose of understanding how it works. Science differs from other disciplines inquiry such as religion and philosophy because its theories and laws rely upon observable physical evidence. (Rachel, VNOS, Q1)

Rachel's view of the empirical NOS was not considered to be fully informed as she did not explicitly articulate an understanding of the role of beliefs and human creativity in science, when prompted by the researcher.

6.2.2 Methods of science

Scientific method - *Science has no single method, rather it relies on the creativity of the investigator to find ways to answer his/her question. Scientists observe, compare, measure, test, speculate, hypothesise, create ideas and conceptual tools, and construct theories and explanations. Scientific knowledge is gained through multiple methods including descriptive and observational methods.*
Aim and general structure of experiments - *An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same. When only one factor at a time is changed or manipulated, the observed result can lead the scientist to assume the factor has either a positive or negative or (none) correlation with the outcome. It is the result of an experiment that will lead the scientist to believe his/her theory has or doesn't have validity. Unlike observations, experiments generally involve elements of control and manipulation of, and intervention in the course of the investigated phenomena (dependent and independent variable, etc.).*
Validity of observationally-based disciplines – *Participants provide examples indicating a clear understanding of the fact that several scientific disciplines are observational in nature and that many powerful scientific theories rest solely on observations. State that manipulative experiments are not required for the development of scientific knowledge (Abd-El-Khalick, 2001, pp. 15-22).*

All of the participants expressed naïve or limited understandings of the methods of science. Rachel, David and Sarah expressed a naïve belief in a step-wise, scientific method, indicating that experiments had a set procedure that needed to be strictly followed. Although Monica, David and Sarah made some references to the controlled nature of experimentation, these participants emphasised that experiments are conducted to ‘prove’ hypotheses or theories, thus expressing a limited understanding of the aim of experiments:

> An experiment is a test (or series of) which prove or disprove particular phenomena. (David, VNOS, Q2)

Rachel was the only participant who expressed partially informed views of the aim and general structure of experiments that included a recognition of the controlled nature of experiments, without an emphasis on proving theories.

All of the participants expressed naïve or limited understandings of the validity of observationally-based disciplines. As many of these participants were unable to articulate accurate definitions of experiments, this was not an unexpected finding. All participants except Tom subscribed to the naïve view that scientific knowledge can only be obtained through the use of experimentation, and that observational data alone are not sufficient for the development of valid scientific knowledge. For example, Rachel stated “It cannot be considered scientific fact until it has been proven through experimentation” (VNOS, Q3). Tom expressed a limited view of the validity of observationally-based disciplines, as although he recognised an initial role for observations in the development of scientific knowledge, he failed to appreciate that many scientific disciplines are primarily based on observational evidence. Regarding scientific observations, he stated:

> I think that's the foundation for all of it, it's very much the foundation of a lot of starting points and then it goes on from there… (Tom, VNOS, Q3)

6.2.3 Theories and laws

Well-supported nature of theories - *Scientific theories are well-established, highly substantiated, elaborate, internally consistent systems of explanations. Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. Scientific theories are concepts that have considerable evidence behind them, and have endured attempts to disprove them.*
Explanatory function of theories – *Appreciation of the significant role that theories play as general guiding frameworks for scientific investigation. Recognition that theories play a major role in generating research problems and guiding future investigations. Investigation can be triggered by scientific theories.*
Difference and relationship between theories and laws - *Scientific laws are statements or descriptions of the relationships among observable phenomena. Scientific theories are inferred explanations for observable phenomena or regularities in those phenomena.*
Recognition that theories and laws are different kinds of knowledge and one cannot become the other. Theories are as legitimate a product of science as laws. Realise that scientists do not usually formulate theories in the hope that some day they would acquire the status of "laws" (Abd-El-Khalick, 2001, pp. 22-29).

All of the participants expressed limited understandings of scientific theories and laws. David expressed a naïve view of the well-supported nature of theories, subscribing to the vernacular meaning of the term 'theory' as a guess or idea:

> A theory is an idea about a phenomenon which may not be able to be proved but which is largely agreed upon by the scientific community, for example, evolution. (David, VNOS, Q5)

This view fails to recognise that scientific theories are well supported, complex, and internally consistent systems of explanations. The other four participants expressed limited views of the well-supported nature of theories that subscribed to the view that theories are conjectural due to a lack of supporting evidence.

Although all of the participants expressed naïve or limited understandings of the well-supported nature of theories, they did appreciate the explanatory function of theories. All of the participants except Tom (who did not directly address this aspect in his responses) expressed partially informed views of the explanatory function of theories which recognised that theories are the most up-to-date available explanations for observable phenomena, and that theories need to be learnt to enable us to develop new knowledge:

> Theories must be learnt as they are correct at the time and many theories, which haven't sufficient supporting evidence, for example, the evolution theory, should be learnt as they provide possible interpretations of the available evidence. (Rachel, VNOS, Q4)

This response is not considered to be fully informed as it does not articulate an understanding of the role of theories in generating research questions and guiding scientific investigations.

Rachel, Monica, David and Sarah all expressed a naïve understanding of the difference and relationship between scientific theories and laws, with many of these participants failing to provide accurate definitions of theories and laws, and stating that theories become laws with the addition of supporting evidence or proof:

> A scientific law has been proven and is agreed upon by all scientists. Whereas a scientific theory is not 100% proved and not all scientists believe it is true…, for example, Newton's laws have been proven whereas there are theories about how the dinosaurs became extinct but none have been completely proven, that's why they're still theories. (Monica, VNOS, Q5)

These participants failed to recognise that theories and laws are different types of knowledge, thus theories cannot become laws.

Tom expressed limited views of the difference and relationship between scientific theories and laws. He did not explicitly state that theories become laws, and his definitions of theories and laws did not focus on proving theories, although his understanding of these concepts was unclear:

> A theory is a work of study that is still undergoing investigation through experiments, inferences and then experiment again. A law involves a field of study where all experiences and experiments follow the said law, for example, the Law of gravity. (Tom, VNOS, Q5)

6.2.4 Tentative NOS

Scientific knowledge, though highly reliable and durable, is at best tentative and 'never' absolute or certain. This knowledge, including facts, theories and laws, is subject to change. Theories change as new evidence, made possible through advances in 'theory' and technology, is brought to bear on existing theories, or as old evidence is re-interpreted in the light of new theoretical advances or shifts in the directions of established research programs. Other factors play as much a significant role in theory change as do new data and technologies. The advancement of new ideas and theories, social and cultural change, and the role of individuals working 'out of context' may be factors that participants believe contribute to theory change (Abd-El-Khalick, 2001, pp. 29-30).

Rachel and Tom expressed partially informed views of the tentative NOS, whilst Monica, David, and Sarah expressed limited views. These assessments were based on individual participants' overall responses to the VNOS questionnaire.

Clarifying the use of key terms such as prove, fact, true, and concrete; provided insight into participants' views of the tentative NOS. The use of such terms implied a tentative stance for both Rachel and Tom, as evidenced in their responses throughout the questionnaire. For example, Rachel's use of the term 'prove' was qualified during interview, and she did not subscribe to an absolutist view, instead she stated:

> I used that very lightly because I know that nothing can really be proven …because there's always going to be another example where it doesn't happen. (Rachel, VNOS, Q3).

Conversely, Monica, David and Sarah's use of key terms implied an absolutist stance. For example, Sarah's emphasis on the terms absolute, proven, concrete, and true, were noted throughout her responses to the questionnaire, with the following example typical:

> …well if you want to find an absolute answer, if you want to make a law about something then putting your own spin on will make it a little bit…well make it less…But I think we are moving towards trying to make everything universal, find an absolute. (Sarah, VNOS, Q9)

David and Sarah expressed limited views of the tentative nature of scientific theories. Although they recognised that theories change, their responses indicated that they believed these changes occur due to new discoveries, information, or technological advances:

> Yes, I think theories do change. Theories change due to deeper more thorough research being performed and with the help of new technologies, i.e., the development of the microscopes led to the discovery of germs, etc. (David, VNOS, Q4)

Conversely, Rachel, Monica and Tom expressed partially informed views of the tentative nature of theories that recognised that theories change, and change is not solely due to new technology or knowledge. These participants' views were not considered to be fully informed as their responses failed to recognise the role of other factors such as social and cultural influences, the re-interpretation of existing evidence, and advances in 'theory' on existing theories.

Monica and Sarah expressed limited views of the tentative nature of scientific laws that failed to recognise that laws are tentative and subject to change. These participants' responses indicated that laws were absolute and unchangeable. Rachel, Tom and David expressed partially informed views of the tentative nature of scientific laws which recognised that laws were changeable, although they were unable to provide any logical reasons to support their view. For example, Rachel was asked whether laws could be disproved and stated "I guess so…I mean it's not impossible" (Rachel, VNOS, Q5).

6.2.5 Inference and theoretical entities

Atoms – *Recognise that atoms cannot be directly observed and only indirect evidence is used to determine the structure of an atom. May indicate that the structure of an atom is a model intended to explain observations of the "behaviour" and/or "properties" of atoms in reaction to various experimental manipulations. Recognition that scientific models are not copies of reality.*
Species - *"Species" is a human construct, or part of a man-made classification system intended to help scientists bring some order to the enormous variety between and among various groups of organisms observed in nature. Like other classification systems, the concept of "species" has some merits. For instance, it helps scientists classify, make sense of the relationships between, and communicate about various organisms. But like all other classification systems, the concept of "species" has limitations and leaves much to be desired. Sharp lines are often difficult to draw among certain groups of organisms that seem to simultaneously belong to more than one species. Such groups of organisms seem to belong to grey areas that span the terrain between the blurred lines that often run between closely related groups of organisms (Abd-El-Khalick, 2001, pp. 33-37).*

Monica and David expressed naïve views of the inferential and theoretical nature of atomic structure that indicated they believed scientists were certain about the structure of atoms because they can directly observe them, although they expressed some uncertainty about their responses due to a lack of knowledge about atomic structure. For example, Monica stated:

> I have always assumed that scientists were certain about the structure of the atom. I think that scientists used microscopes and did tests on the atoms…but I have no idea…I don't even know if they can actually see the atom. (Monica, VNOS, Q6)

This response fails to recognise the inferential nature of atomic structure, that atoms are created models, and cannot be directly observed. David's response indicated a faith in the work of scientists:

> I have put my faith in the honesty of the scientists. This observation is the only one I am aware of and no-one has ever disputed it to my knowledge, so it must be true. I think many experiments have been made to test the accuracy of the evidence and suspect the electron microscope played a part. …I'd put my faith in the fact that we've been taught that ever since I was a boy or since high school anyway that that's what made up an atom, I put my faith in the honesty of the scientists… (David, VNOS, Q6)

Rachel expressed a limited understanding of the inferential and theoretical nature of atomic structure, as although she expressed that scientists are unsure about the structure of atoms, she attributed this uncertainty to not being able to directly observe atoms. She also expressed unfamiliarity with the history of atomic structure in general.

Tom and Sarah expressed partially informed views of the inferential nature of atomic structure which recognised that scientists are uncertain about the structure of the atom and expressed an understanding of the role of indirect evidence in determining the structure of the atom:

> Through the use of probable orbital clouds where the electrons can be found …it can be said that scientists are uncertain of the exact structure. Through the experiences of photon emissions and such experiments, they aid in determining an atom's make up. (Tom, VNOS, Q6)

Rachel expressed a naïve view of the inferential and theoretical nature of the concept of 'species,' as her response indicated that scientists are fairly certain about the notion of species due to observable evidence such as DNA. She failed to recognise the inferential nature of species as a created construct:

> I think the concept of a species can be determined from the DNA of blood samples and that scientists can be fairly certain about the accuracy of this evidence in characterising a species. (Rachel, VNOS, Q7)

Monica and David expressed limited understandings of the notion of species that again relied on observable evidence and failed to recognise the inferential nature of the construct, although David expressed uncertainty about the construct with reference to the existence of mules, and Monica mentioned a set of criteria in addition to DNA evidence in her response.

As with the atomic structure example, Tom and Sarah both expressed partially informed views of the notion of species that recognised the uncertainty of the construct, and an understanding of the inferential nature of the construct:

> I think species is an arbitrary title given to any group of organism that fits its generation, and if organisms don't fit it they are divided and classed further or

> separately, for example, if two organisms cannot interbreed they are different species. (Sarah, VNOS, Q7)

6.2.6 Subjective and theory-laden NOS

Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, previous knowledge, training, experiences, and expectations influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge (Abd-El-Khalick, 2001, pp. 38-41).

Rachel, Tom, David and Sarah expressed limited views of the subjective and theory-laden NOS. Tom simply cited scientific data in his response to Q8 and did not explicitly consider the possible interpretations of this data by different scientists. Rachel, David and Sarah made reference to a lack of conclusive or complete evidence to enable the problem to be solved, in their responses. For example, Rachel articulated that different interpretations are possible from the same data, but she indicated that a lack of evidence allows scientists to 'fill in the gaps' with interpretation:

> …not enough proof really of what happened and so people can be free to use their imagination of what happened and if the evidence isn't clear enough they can construe it which way they want. (Rachel, VNOS, Q8)

Her references to 'vices,' 'construe,' and 'bias' throughout the questionnaire also indicate that human interpretations may be negative and undesirable. David expressed a similar response:

> Because scientists are human, the evidence is not conclusive and therefore open to opinion which is a trait of the human brain… (David, VNOS, Q8)

All of these participants' references to a lack of conclusive evidence implies a reliance on a sufficient quantity of data to solve the problem. Monica was the only participant who expressed partially informed views of the subjective and theory-laden NOS that recognised scientists may interpret the same data in different ways, although she did not explicitly explain why this would happen, and her response focused on personal not professional subjectivity:

> Because data can be interpreted differently. …everyone has different interpretations of certain things and I guess their background and what they believe in… (Monica, VNOS, Q8)

6.2.7 Social and cultural NOS

Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy and religion. Recognition that social and cultural factors influence 'how' science is practiced (Abd-El-Khalick, 1998).

Rachel, Tom, David and Sarah expressed limited views of the social and cultural NOS. Although Rachel and Sarah recognised the influence of social and cultural factors on science, their responses implied that these influences promote bias in science, and implied a negative stance:

> No human can approach a study in a completely unbiased way because they are influenced by their own history and social and cultural values. (Rachel, VNOS, Q9)

Sarah indicated that science is moving from “a social and cultural reflection to a universal discipline… I think we are moving towards trying to make everything universal, find an absolute” (VNOS, Q9). She indicated that science will always be biased by interpretation, which hinders moving towards absolute knowledge. Her emphasis on ‘absolute’ was evident throughout the questionnaire.

David also displayed a limited view of the social and cultural NOS. His response implied that there is a common set of ‘universal’ understandings about science, thus displaying a limited understanding of science as a human endeavour that is carried out, and influenced by the culture in which it is practiced.

Tom expressed uncertainty in response to this question and cited the Manhattan Project as an example of a scientific endeavour which was “created, financed and driven by the needs of a political and cultural need to reduce/minimise U.S. military losses” (VNOS, Q9). This expressed uncertainty regarding the influence of social and cultural factors implies a shift from thinking about science as universal, but could not be classified as partially informed or informed as Tom does not explicitly express that these factors influence ‘science.’

As with the subjective and theory-laden NOS, Monica was the only participant to express partially informed views of the social and cultural NOS that recognised the impact of these influences on scientific knowledge:

> I think that science can reflect social and cultural values, for example, some cultures do not believe that humans evolved from apes because of their religious beliefs and their social and cultural values. (Monica, VNOS, Q9)

6.2.8 Creative and imaginative NOS

Imagination and creativity are needed in scientific investigation and permeate all stages of scientific investigation. Use of the term "creativity and imagination" refers to the 'invention' of explanations, models or theoretical entities. Creativity influences the interpretation of data (Abd-El-Khalick, 2001, pp. 30-33).

Rachel, Monica, Tom and David expressed limited views of the creative and imaginative NOS as they failed to recognise the role of creativity and imagination throughout all stages of scientific investigation. For example, Rachel indicated that, although scientists can use their creativity and imagination during the planning and design stages of scientific investigation, she expressed:

> I'm not sure about the interpreting the data because I mean I suppose they should think they probably do use their imagination a bit but not really appropriate a lot of the time because you can't be too imaginative. (Rachel, VNOS, Q10)

This view indicates that the use of creativity and imagination may be undesirable and introduce bias to scientific investigation. Similar views were expressed by Tom, who also highlighted that creativity and imagination should not be used during data collection. David also indicated that creativity and imagination should only be used during the early stages of scientific investigation, but his use of the term 'creative and imaginative' was more aligned with 'thinking broadly' and being ‘open-minded’ rather than using the term to refer to the construction of scientific models and theories:

> Yes, I do think scientists use their imaginations and creative skills when researching. It broadens their thinking, they explore the unthinkable. I don’t think science would have developed as far as it has if scientists and researchers wore ‘blinkers’. I think scientists imaginations should be the most fertile at the outset of research and then become ‘optimistically controlled’ towards the end as the picture becomes more clearer, for example, cancer research. (David, VNOS, Q10)

Many of these participants also expressed naïve or limited views of the inferential NOS regarding atomic structure and the construct of species, further supporting the notion that these participants displayed a limited understanding that failed to recognise that many concepts in science are invented, and rely on indirect evidence.

Sarah was the only participant who expressed partially informed views of the creative and imaginative NOS, as she recognised that scientists use creativity and imagination during all stages of scientific investigation:

> I believe scientists use their creativity and imagination throughout all stages of good experiments as they need to think broadly to consider all possibilities, for example, planning and design – design best, new way to perform experiment; data collection – consider all sources of data, relevant data and influences on data. (Sarah, VNOS, Q10)

Her view was not considered to be fully informed, as her use of the term 'creativity and imagination' did not refer to the construction of scientific models and theories. As with the other participants, Sarah's reference to the term creativity and imagination was aligned with 'thinking broadly' and being 'open-minded.'

6.3 Post-intervention views of NOS

All of the participants expressed naïve and/or limited views of six or more of the eight examined NOS aspects at the commencement of the study. Many positive changes were evident at the end of the intervention with four of the five participants (Rachel, Monica, Tom and Sarah) expressing partially informed and/or informed views of five or more of the eight examined NOS aspects. These four participants experienced development in at least five of the eight examined aspects. David's largely naïve and/or limited views of the examined NOS aspects remained relatively unchanged at the conclusion of the intervention.

Participants' responses to the VNOS-C questionnaire, and follow up interviews administered at the conclusion of the study will be presented and analysed in this section. Participants' views of each of the eight examined NOS aspects will be discussed in separate sub-sections. Similarly to Section 6.2, a summary statement (adapted from Abd-El-Khalick, 1998) representing an informed view of each examined NOS aspect will be provided at the beginning of each sub-section. Full details of the coding rubrics for each of the examined NOS aspects are provided in Appendix I. Segments of transcript will be utilised to provide support for the assessments provided by the researcher. A summary of individual participants' views of each of the examined NOS aspects is provided in Table 6.1.

6.3.1 Empirical NOS

Scientific knowledge is empirically based and is generally derived from observations of natural phenomena, and these observations are always influenced by human assumptions and previous knowledge (and are thus theory-laden). Science involves the formulation of ideas (e.g., hypotheses, theories). Evidence is then sought to either support or discount these ideas, which is different to religion. Regarding the term 'empirical', participants expressing an informed view of this aspect of NOS do not indicate that tangible data can be used to 'prove' scientific claims or that science is based on observations of phenomena to the exclusion of other personal, social or cultural attributes. Even though science relies on evidence and observation, there is much in science that is based on belief, convention, and the non-observable (Abd-El-Khalick, 2001, pp. 13-15).

Rachel, Monica, and Tom showed development in their view of the empirical NOS. Rachel expressed an informed view of the empirical NOS stating:

> Science is the human discipline which works towards understanding the natural processes of the Earth and beyond and often manipulating or reproducing these processes in experimentation for societal benefit… (Rachel, VNOS, Q1)

This response showed a recognition that although scientific knowledge is generally based on empirical observations, human interpretations and pre-conceived notions play a role in the development of this knowledge. Although Monica did not explicitly refer to empirical evidence in her response, she did not subscribe to the naïve view she expressed at the beginning of the intervention, whereby science seeks to prove theories or phenomena, and she now recognised the influence of previous knowledge and social and cultural ideas on scientific knowledge:

> Science is a way of explaining the things around us. It is not absolute as it does change as technology and knowledge advances. Different societies and cultures, and the people within them, may explain the same thing differently to others around the world because of their different background. I think science is different from religion and philosophy as scientists can do experiments to obtain results to draw conclusions whereas religion and philosophy cannot. (Monica, VNOS, Q1)

Tom's use of absolutist terms such as concrete and factual were absent from his post-intervention responses. He expressed partially informed views that indicated an understanding that science is based on empirical evidence, and he also made reference to the influence of human beliefs and interpretation on scientific knowledge in some of his responses to the questionnaire.

David and Sarah's view of the empirical NOS remained largely unchanged at the conclusion of the intervention. They expressed limited views which failed to recognise that although scientific knowledge is generally derived from observational evidence, these observations are influenced by human assumptions and previous knowledge. Their use of the terms real, concrete and fact, implied that empirical evidence has the sole role in the development of scientific knowledge:

> Science is the study of real things and can be supported by facts. Religion and philosophy are abstract concepts driven by human emotion. (David, VNOS, Q1)

6.3.2 Methods of science

Scientific method *- Science has no single method, rather it relies on the creativity of the investigator to find ways to answer his/her question. Scientists observe, compare, measure, test, speculate, hypothesise, create ideas and conceptual tools, and construct theories and explanations. Scientific knowledge is gained through multiple methods including descriptive and observational methods.*
Aim and general structure of experiments *- An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same. When only one factor at a time is changed or manipulated, the observed result can lead the scientist to assume the factor has either a positive or negative or (none) correlation with the outcome. It is the result of an experiment that will lead the scientist to believe his/her theory has or doesn't have validity. Unlike observations, experiments generally involve elements of control and manipulation of, and intervention in the course of the investigated phenomena (dependent and independent variable, etc.).*
Validity of observationally-based disciplines *– Participants provide examples indicating a clear understanding of the fact that several scientific disciplines are observational in nature and that many powerful scientific theories rest solely on observations. State that manipulative experiments are not required for the development of scientific knowledge (Abd-El-Khalick, 2001, pp. 15-22).*

All five participants showed development in their views of the methods of science. Rachel, Monica and Tom showed development from a limited to a partially informed view, and David and Sarah showed some minor developments in their views, from naïve to limited views.

Monica expressed an informed view of the 'scientific method' that recognised that there is no strict, singular method to conduct scientific investigations, and scientists use a variety of methods to help answer their questions. Tom expressed a partially informed view which recognised the limitations of a strict 'scientific method' but emphasised approaching scientific investigations from different viewpoints:

> ...need to approach problems from varying views to obtain and maximise our outcomes…Because standard practices themselves will only lead to a finite level… (Tom, VNOS, Q10)

Rachel and Sarah were not explicitly asked about the ‘scientific method’ during the post-intervention interview, although it should be noted that neither of them made reference to the existence of strict method for conducting scientific investigations in any of their responses. David’s view of the ‘scientific method’ improved slightly from a naïve to a limited view. When asked whether scientists use a specific method or stepwise procedure when they conduct experiments, David expressed initial uncertainty, and then stated “…there is probably somewhere in the world a framework for how you test something, a generic, testing procedure for what you do first” (VNOS, Q2), thus subscribing to the limited view of the existence of a general method of scientific investigation.

Rachel, Monica, Tom and Sarah expressed partially informed or informed views of the aim and general structure of experiments at the conclusion of the intervention. Tom showed the biggest improvement, from the limited view he expressed at the commencement of the study which failed to mention the controlled nature of experimentation, to an informed view:

> An experiment is where all but one given variable is controlled. This change in variable allows us to observe the reaction/interaction, record the occurrences and therefore draw an interpretation from the data. (Tom, VNOS, Q2)

Monica and Sarah’s views of the aim and general structure of experimentation improved from limited to partially informed views. These participants no longer explicitly expressed that experiments are conducted to prove theories:

> An experiment is a controlled, planned event in which the experimenter seeks to find an answer to a defined problem regarding the cause and effect of interactions of substances and bodies, or the relationship between interacting substances and bodies. (Sarah, VNOS, Q2)

David was the only participant who did not express an improvement in his limited view of the aim and general structure of experiments, and still emphasised that experiments were conducted to prove theories.

Rachel and Tom expressed partially informed views of the validity of observationally-based disciplines at the conclusion of the study. Rachel showed a substantial improvement in the naïve view she expressed at the commencement of the study, to a view that recognised the role and validity of observational evidence, in addition to experimentation, in the development of scientific knowledge, stating “...I think observations is just as valid as doing experiments” (VNOS, Q3). Tom also recognised the role of observations in science, although his response indicated that observations are primarily used when experimentation is unavailable “…whilst examining phenomena, it can allow, we can use that to interpret data but we don’t actually need to experiment on it because we can’t at this stage” (VNOS, Q3).

Monica, David and Sarah views of this aspect did not substantially improve over the duration of the intervention. These participants still expressed that experiments are needed for the development of scientific knowledge, and excluded the use of observational evidence in science. David provided an interesting response when asked whether astronomy was a science:

> Well astronomy's definitely a science…maybe these two interviews and everything we did in the subject is now starting to make me think that up till now I've been just agreeing with science blindly… (David, VNOS, Q3)

This comment illustrates a recognition of dissonance between David's pre-existing views and ideas introduced during the course.

6.3.3 Theories and laws

Well-supported nature of theories - *Scientific theories are well-established, highly substantiated, elaborate, internally consistent systems of explanations. Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. Scientific theories are concepts that have considerable evidence behind them, and have endured attempts to disprove them.*
Explanatory function of theories – *Appreciation of the significant role that theories play as general guiding frameworks for scientific investigation. Recognition that theories play a major role in generating research problems and guiding future investigations. Investigation can be triggered by scientific theories.*
Difference and relationship between theories and laws - *Scientific laws are statements or descriptions of the relationships among observable phenomena. Scientific theories are inferred explanations for observable phenomena or regularities in those phenomena.*
Recognition that theories and laws are different kinds of knowledge and one can not become the other. Theories are as legitimate a product of science as laws. Realise that scientists do not usually formulate theories in the hope that some day they would acquire the status of "laws" (Abd-El-Khalick, 2001, pp. 22-29).

Theories and laws was the least developed NOS aspect assessed in this intervention. Rachel, Monica, Tom and David showed no substantial improvement in their overall understanding of this multi-faceted aspect, with their views remained limited. Sarah's views improved from a limited to partially informed position at the end of the intervention.

Rachel, Monica, Tom and David's naïve and/or limited views of the well-supported nature of scientific theories remained relatively unchanged at the conclusion of the intervention. These participants still subscribed to the common misconception that theories are speculative as they do not have enough empirical evidence to support or prove them. Sarah's views of this aspect showed some improvement as she recognised that theories are invented explanations for phenomena, supported by a body of evidence:

> Theories are conceptual models derived from evidence and reasoning which explain, to the best of our ability, a phenomenon, for example, theory of evolution... (Sarah, VNOS, Q5).

Participants' views of the explanatory function of scientific theories also remained relatively unchanged at the conclusion of the intervention, although it should be noted that the participants had previously expressed partially informed understandings of this aspect at the commencement of the study. For example, Monica recognised the important role theories have in informing and directing scientific investigations, and that learning theories enables students to see how scientific ideas have developed over time. She referred to the example of the development of the atomic theory discussed during a class session, in her response:

> Even though scientific theories do change, it is important to learn them as they may help others develop the theory further. I was thinking with that one, the atomic theory, and how if scientists hadn't have seen how it had progressed from past ones, and even how that theory came about, they probably wouldn't have reached where they are now. (Monica, VNOS, Q4)

All of the participants continued to express naïve and/or limited understandings of the difference and relationship between scientific theories and laws. These participants were unable to provide accurate definitions of theories and/or laws, and many subscribed to the belief that theories become laws when proven. Sarah showed a slight improvement in her view from a naïve to a limited view as she was able to correctly define theories in her post-intervention response.

Rachel, Monica, Tom and David were asked whether they could rank theories and laws in their post-intervention interview. Rachel responded with a naïve view that specified laws should be ranked higher than theories, and although David expressed that he would "put them side by side" (VNOS, Q5), he continued to express the limited view that laws are proven, and theories are speculation. Monica and Tom recognised that theories are legitimate products of science, and chose not to rank laws higher than theories:

> Well, I think they are quite different… I think that you couldn't rank them, they're both very important in learning science. (Monica, VNOS, Q5)

6.3.4 Tentative NOS

Scientific knowledge, though highly reliable and durable, is at best tentative and 'never' absolute or certain. This knowledge, including facts, theories and laws, is subject to change. Theories change as new evidence, made possible through advances in 'theory' and technology, is brought to bear on existing theories, or as old evidence is re-interpreted in the light of new theoretical advances or shifts in the directions of established research programs. Other factors play as much a significant role in theory change as do new data and technologies. The advancement of new ideas and theories, social and cultural change, and the role of individuals working 'out of context' may be factors that participants believe contribute to theory change (Abd-El-Khalick, 2001, pp. 29-30).

Rachel, Monica, and Tom expressed partially informed and/or informed views of the tentative NOS, whilst David and Sarah's views of this aspect remained limited. These assessments were based on individual participants' overall responses to the VNOS questionnaire. Monica showed a substantial improvement in her view of this aspect from a limited to an informed view. Interestingly, the other four participants' views of this aspect did not significantly improve, although it should be noted that Rachel and Tom already expressed partially informed views of this aspect at the commencement of the study.

As reported in the pre-intervention section (refer to Section 6.2 for more details), clarifying the use of key terms such as prove, fact, true, concrete, provided insight into participants' views of the tentative NOS. Rachel and Tom's use of such terms implied a tentative stance, as evidenced in their responses throughout the questionnaire, in both their pre- and post-intervention responses. For example, Tom's use of terms such as prove were qualified during the post-intervention interview. When he was asked how scientists prove something, Tom responded:

> Well, I think proof is not so much proof, but experimenting and coming up with similar conclusions or running models and coming up with similar conclusions. (Tom, VNOS, Q1)

Monica’s use of key terms improved over the duration of the intervention. Her use of these terms now reflected a tentative stance, as evidenced in her response to a prompt provided in the post-intervention interview. She had expressed that the periodic law can be proven in response to Q5 of the VNOS. When asked how scientists prove something she stated “Maybe because there’s more evidence to show or to explain it” (VNOS, Q5).

David and Sarah’s use of key terms were still dominated by absolutist views of scientific knowledge, and they continued to express limited views of the tentative nature of scientific theories at the conclusion of the study.

Rachel and Tom’s views of the tentative nature of scientific theories did not substantially improve over the duration of the intervention, but importantly they expressed partially informed views of this aspect at the commencement of the study. Monica’s view of this aspect improved from a partially informed to informed view as she recognised the role of advances in ‘theory,’ and the reinterpretation of existing evidence on theory development:

> Yes, scientific theories do change…it is important to learn them as they may help others develop the theory further. I was thinking with that one the atomic theory and how if scientists hadn’t have seen how it had progressed from past ones, and

> even how that theory came about, they probably wouldn't have reached where they are now. (Monica, VNOS, Q4)

Monica also showed improvement in her understanding of the tentative nature of scientific laws, from a limited view to a partially informed view that recognised all scientific knowledge is tentative. Rachel, Tom, David, and Sarah's view of this aspect remained largely unchanged at the conclusion of the study.

6.3.5 Inference and theoretical entities

***Atoms** – Recognise that atoms cannot be directly observed and only indirect evidence is used to determine the structure of an atom. May indicate that the structure of an atom is a model intended to explain observations of the "behaviour" and/or "properties" of atoms in reaction to various experimental manipulations. Recognition that scientific models are not copies of reality.*
***Species** - "Species" is a human construct, or part of a man-made classification system intended to help scientists bring some order to the enormous variety between and among various groups of organisms observed in nature. Like other classification systems, the concept of "species" has some merits. For instance, it helps scientists classify, make sense of the relationships between, and communicate about various organisms. But like all other classification systems, the concept of "species" has limitations and leaves much to be desired. Sharp lines are often difficult to draw among certain groups of organisms that seem to simultaneously belong to more than one species. Such groups of organisms seem to belong to grey areas that span the terrain between the blurred lines that often run between closely related groups of organisms (Abd-El-Khalick, 2001, pp. 33-37).*

Rachel, Tom and Sarah expressed partially informed and/or informed views of the inferential and theoretical NOS, whilst Monica and David expressed naïve and/or limited views. Rachel and Sarah's views of this aspect developed over the course of the intervention, whilst Monica and David's views of this aspect remained naïve and /or limited. Tom's views also remained largely unchanged although he already expressed partially informed views of this aspect at the commencement of the study.

Tom and Sarah expressed an understanding of the inferential nature of atomic structure that recognised scientists are uncertain about the structure of an atom, and use indirect evidence to aid in creating a possible structure. They made references to the concept of 'scientific models' used to explain the properties and behaviours of atoms in their responses. For example, Sarah stated:

> Scientists are uncertain about the exact structure of atoms, but know of their components and perform experiments to create a general model of the structure. Experiments involving the electrons and the protons can be performed based on ideas about the charges of these particles and the results of these manipulations observed to identify a possible structure… (Sarah, VNOS, Q6)

Although Rachel still expressed a reliance on the use of direct evidence with regard to atomic structure, her post-intervention interview response indicated some understanding that an atom is a created model:

> … I think that scientists developed their current model by observing the behaviour of atoms within a substance under certain conditions and using their imaginations to visualise the relationship between the nucleus, protons, neutrons and electrons. (Rachel, VNOS, Q6)

Monica and David's views of atomic structure remained naïve and/or limited at the conclusion of the study. During his post-intervention interview, David was asked to clarify how scientists know about atoms if they cannot directly observe them:

> Well, that's one of those silly things that I can't explain… Right now I've never seen one, I put my faith in science… I suppose its part of my personality, my psyche, I'm just scientifically inclined. And I blindly believe the scientists. (David, VNOS, Q1)

This response mirrors his pre-intervention view, and indicates an over-reliance on the integrity of science as an elite profession, rather than focusing on the importance of empirical evidence, and the construction and substantiation of scientific theories, in the development of scientific knowledge.

Sarah and Rachel showed development in their views of the inferential notion of species, expressing partially informed and/or informed view of this aspect. They both recognised that the concept of species is uncertain, and developed by humans in an attempt to classify a wide variety of organisms:

> I believe that scientists decided that 'the ability to interbreed and produce fertile offspring' was the definition of a species, and fit organisms into the hierarchy to suit this definition. If there is further differentiation they wish to note, sub-species are recorded, but at the level of species that is the arbitrary definition… (Sarah, VNOS, Q7)

Monica, David and Tom's views of this aspect remained relatively unchanged over the duration of the intervention, although Tom already held partially informed views of this aspect. Monica and David's limited understandings of this aspect remained largely unchanged at the conclusion of the study.

6.3.6 Subjective and theory-laden NOS

Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, previous knowledge, training, experiences, and expectations influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge (Abd-El-Khalick, 2001, pp. 38-41).

Participants' views of the subjective and theory-laden NOS improved substantially over the course of the intervention. Rachel, Monica, Tom, and Sarah all showed improvement in their understanding of this aspect, and displayed partially informed and/or informed understandings of this aspect at the conclusion of the study. David's views of this aspect did not significantly improve, and remained limited at the conclusion of the study.

Rachel showed a major change in her view of the subjective and theory-laden NOS, from a limited view to an informed view. She made numerous references to this aspect during her post-intervention interview. With regard to Q8 of the VNOS, she no longer made reference to a lack of data leading to differing interpretations. Her responses reflected an understanding that different theoretical orientations and beliefs influence the interpretation of data:

> …Different interpretation of initial data based upon pre-conceived theories and personal beliefs can lead to completely different conclusions. (Rachel, VNOS, Q8)

Monica also showed development in her view of the subjective and theory-laden NOS, from a partially informed view to an informed view, and these views were evident in her responses throughout the VNOS questionnaire, and during follow-up interviews. Tom and Sarah showed development in their views of the subjective and theory-laden NOS, from limited to partially informed views. They noted that scientists interpret the same data differently, although their responses only focused on personal, not professional subjectivity. For example, Tom stated:

> …ah, I think it's more their background…in the background they've been brought up to believe, if they're more of a volcanologist leaning or astrological leaning, I think that has a lot to influence, and themselves what they've personally experienced, if they've gone out and seen volcanic layers, debris they'd be more tending to believe that way whereas if they've gone out and been on more impact sites and checked… they'd probably be more… (Tom, VNOS, Q8)

David's limited views of the subjective and theory-laden NOS remained largely unchanged over the duration of the intervention.

6.3.7 Social and cultural NOS

Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy and religion. Recognition that social and cultural factors influence 'how' science is practiced (Abd-El-Khalick, 1998).

Participants' views of the social and cultural NOS also improved substantially over the course of the intervention. Rachel, Monica, Tom, and Sarah all expressed partially informed or informed views of this aspect at the conclusion of the study, with Rachel, Tom and Sarah displaying improved understandings of this aspect. Monica's view of the social and cultural NOS did not significantly improve, although she already held partially informed views of this aspect, and David's views remained limited and unchanged at the end of the intervention.

Rachel's view of the social and cultural NOS improved substantially from a limited to an informed view as she stated:

> I believe that science reflects social and cultural values because I believe that all human activity is bound to the values and beliefs an individual or group of people acquire through lived experiences… (Rachel, VNOS, Q9)

This view is more developed than her initial view as there is less emphasis on social and cultural influences 'biasing' science, and a recognition that these influences affect how science is practiced. Tom and Sarah also expressed development in their understanding of the social and cultural NOS from a limited to partially informed position. Tom's initial uncertainty about the influence of social and cultural factors on scientific practice expressed at the beginning of the study appeared to be resolved at the conclusion of the study. Previously, he expressed uncertainty as to whether social and cultural factors influenced science and cited the Manhattan Project as a possible example of this influence. In his post-intervention response he expressed confidence in citing this example, stating:

> No need to go past the Manhattan Project where Einstein, himself, implored Roosevelt to pursue the power of the atom out of fear of fascism reaching it first. Also, there is no such thing as pure science for the science, but science research is always carried out with a financial or social dividend in mind. So there’s always that pressure at the back of it, there’s no such thing as science for science purposes. (Tom, VNOS, Q9)

There was no substantial change in Monica’s understanding of the social and cultural NOS, although she did hold partially informed views of this aspect at the commencement of the study. David’s views of the social and cultural NOS also remained largely unchanged. He expressed limited views of this aspect, and although he recognised that social and cultural factors influenced science, he implied that these influences may be biased or negative:

> If your culture is strong in social and religious values, your view on a scientific phenomenon may be biased... (David, VNOS, Q9)

6.3.8 Creative and imaginative NOS

Imagination and creativity are needed in scientific investigation and permeate all stages of scientific investigation. Use of the term “creativity and imagination” refers to the ‘invention’ of explanations, models or theoretical entities. Creativity influences the interpretation of data (Abd-El-Khalick, 2001, pp. 30-33).

Participants’ views of the creative and imaginative NOS improved substantially over the duration of the study. Rachel, Monica, Tom, and Sarah all expressed partially informed views of this aspect at the conclusion of the study, with Rachel, Monica and Tom showing improvement in their views. Sarah’s views of this aspect showed no substantial improvement, although she did express partially informed views at the commencement of the study. David's limited views of the creative and imaginative NOS remained largely unchanged at the end of the intervention.

Rachel, Monica and Tom showed positive changes in their views of the creative and imaginative NOS from limited to partially informed views. These participants recognised that creativity and imagination are needed during all stages of scientific investigation, and that the use of creativity and imagination during scientific investigations was neither undesirable, nor did it create bias. Participants' often equated the term 'creative and imaginative' to being 'open-minded' or 'thinking outside the square,' thus not showing a fully informed understanding of this aspect that aligned these terms with 'the construction of scientific explanations.' For example, Tom noted:

> …Yes, because we wouldn't expand our knowledge unless we explore the 'what if' questions. We need to approach problems from varying views to obtain and maximise our outcomes… This is best done by thinking outside standard practices. (Tom, VNOS, Q10)

Sarah's partially informed views of the creative and imaginative NOS remained largely unchanged over the course of the intervention. She also recognised that creativity and imagination are needed during all stages of scientific investigation. David expressed limited views of the creative and imaginative NOS, and his views of this aspect remained largely unchanged over the course of the intervention. He continued to subscribe to his previously stated belief that creativity and imagination are limited to certain stages of scientific investigation:

> …I think scientists do use an element of imagination and creativity as this broadens their perspective when researching an issue and I think this is a good approach. However, as the research becomes more refined and closer to concluding, the scientists need to become the opposite, i.e., they need to be more focused on the facts and not let emotion get in the way of their decisions. (David, VNOS, Q10)

His limited view of the creative and imaginative NOS was further reinforced by his largely naïve views of inference and theoretical entities that failed to recognise that both ‘atoms’ and ‘species’ are human-developed constructs.

6.4 Summary

Four of the five preservice teachers’ views of NOS changed from less desirable understandings of NOS to more desirable understandings of NOS over the duration of the intervention. Rachel and Monica exhibited development in six of the eight examined aspects, and Tom and Sarah showed development in five of the eight examined aspects. Rachel and Tom expressed partially informed or informed views of seven of the eight aspects, Monica exhibited partially informed or informed views of six of the eight aspects, and Sarah expressed partially informed or informed views of five of the eight aspects. David failed to exhibit substantial development toward more desirable understandings of the examined aspects of NOS, with development noted in relation to one of the examined NOS aspects. He expressed naïve and/or limited views of all eight examined NOS aspects at the conclusion of the study.

Participants' views of the subjective and theory-laden NOS, the social and cultural NOS, and the creative and imaginative NOS, were the most developed aspects of NOS assessed in this study. Four participants expressed naïve or limited views of these aspects at the commencement of the study, and at the end of the study four participants expressed partially informed or informed views of these aspects. These participants expressed an understanding of the role of previous beliefs and experiences on the interpretation of scientific data, the impact of social and cultural values on the practice of science, and the role of creativity and imagination during all stages of scientific investigation.

Conversely, participants' views of theories and laws were the least developed aspect of NOS assessed in this study. All participants displayed naïve or limited views of this aspect at the commencement of the study. Four of the five participants still subscribed to naïve or limited views of this aspect at the conclusion of the study. These participants did not recognise the well-supported nature of scientific theories, and did not express an understanding of the difference and relationship between scientific theories and laws.

The following section will identify trends in the data by analysing and comparing participants' VNOS-C profiles, and their final interview transcripts pertaining to NOS.

6.5 Trends in the data

An analysis and comparison of participants' VNOS-C profiles and final interview transcripts pertaining to NOS, indicated three important trends in the data: (a) alignment of NOS views between VNOS-C and interview transcripts, (b) impact of perceived previous knowledge about NOS, and (c) recognition of the importance or usefulness of NOS. These trends will be discussed in the following sub-sections.

6.5.1 Alignment of NOS views between VNOS-C and interview transcripts

An examination of participants' definitions of NOS expressed in the final interview corresponded positively to the aspects of NOS that developed most substantially in the VNOS-C. When the participants were asked to describe or define NOS in their own words, all of the participants made reference to either the subjective and theory-laden NOS, or the social and cultural NOS, or both of these aspects. For example, in the final interview Monica stated:

> Well, I guess one of the main things for me is that different people have different opinions and their values, backgrounds, experiences can influence their opinions, or how they view a particular thing in science. Just that science isn't absolute, it's changing. (Monica, Final interview)

This response corresponded with her post-intervention views of NOS, as expressed in the VNOS-C:

> Different societies and cultures, and the people within them, may explain the same thing differently to others around the world because of their different background. (Monica, VNOS, Q1)

> Different conclusions are possible from the same set of data, as different scientists have differing backgrounds, values, beliefs and training. These all contribute to the way they draw conclusions from data... (Monica, VNOS, Q8)

References to the tentative NOS and the empirical NOS were also evident in one or two of the participants' final interview responses. Sarah was the only participant who made a reference to scientific theories and laws in her response. It is important to note that she was the sole participant who displayed development in her understanding of this NOS aspect, from a limited to a partially informed view in the VNOS-C. Her final interview response indicated an understanding that scientific theories are constructed by people, and are supported by evidence and data:

> I'd say science is developed by people over time, by experimenting and discussing and debating different perspectives, bringing different ideas and backgrounds together with evidence and data to construct concepts and theories and laws about science. (Sarah, Final interview)

Sarah's final interview response corresponded with her post-intervention view of scientific theories and laws, as expressed in the VNOS-C:

> Theories are conceptual models derived from evidence and reasoning which explain, to the best of our ability, a phenomenon, for example, theory of evolution... (Sarah, VNOS, Q5)

Thus, from the participants' own self reports, the aspects of NOS they showed the most substantial development in, were also the aspects of NOS they predominantly cited when asked to define or describe NOS in their own words.

An interesting response was given by David (the only participant whose largely naïve views of NOS did not substantially develop over the course of the intervention), when asked to define or describe NOS in his own words. He expressed some confusion over the meaning of the question, and required clarification of what was meant by 'NOS.' When the researcher attempted to clarify the question by prompting him to think about how he could describe an aspect of NOS, he responded:

> Long pause (laughs) Aspects? What's an example of the NOS? That's a bit over my head, that one. …To me, the characteristics that describe what science is. The NOS is the characteristics of science and all that it encompasses. …Long pause…Social ramifications, ethical implications, commercial applications, theological connections. (David, Final interview)

David's lack of ability to articulate his own definition of NOS, without prompts, is evident in the above quote. This is not an unexpected findings as David's views of the examined NOS aspects as measured by the VNOS-C showed no overall development, and remained naïve and/or limited at the conclusion of the study.

6.5.2 Impact of perceived previous knowledge about NOS

Another trend emerged during the final interview when participants were asked whether they had learnt about NOS during the course. During the final interview, Tom, David and Sarah expressed that they had previously learnt about NOS. Tom stated that he had "not so much learned, a lot was refreshed on what's been brought up to me in the past" (Final interview). When he was asked whether he could not pinpoint any specific aspects or instances of NOS introduced in the course, he commented:

> …almost everything we did was building upon stuff that I had read about or actually experienced myself. I had the added benefit of being in a science based industry as well as having done senior chemistry and physics and being taught by a teacher that was a chemical engineer himself, so a lot of the stuff was not new, it was just refreshing. So there wasn't one instance where I could say well that was an introduction of a new thought. (Tom, Final interview)

This quote implies that Tom attributed his science background to contributing toward his understanding of NOS. This quote was provided at the start of the final interview. Interestingly, his confidence in his pre-existing ideas about NOS was mediated towards the end of the final interview, when he was asked whether his view of NOS had changed from the beginning of the course, Tom noted "Oh, it's changed a little bit, I think I've learnt something, yeah. It was hard, when I was writing, to put a pinpoint on it" (Final interview). Tom was not explicitly asked whether he had heard of NOS in his initial interview.

An examination of David and Sarah's initial interview transcripts revealed that David and Sarah expressed that they had not heard of NOS before, although in their final interviews they provided responses to the contrary. For example, in the final interview, David expressed that he already knew about NOS and nothing in the course was an introduction of a new idea or aspect, even though he had struggled to provide a description of NOS in the previous question:

> I think that I knew about them, to the point that I was happy with what I thought about them. I don't recall anything happening where it threw me into deep thought, and I thought 'well I hadn't thought of that. (David, Final interview)

Sarah also expressed that she already knew about many of the aspects of NOS introduced in the course, but did mediate this response in the final interview by noting that she had learnt about NOS in the course:

> Yeah, it was kind of stuff that I already knew, like it was a lot of general things like obviously science is not a clearly defined body of knowledge and it's not something that only certain people can tap into. Like I didn't have the perception of science as an elitist kind of field like that, but that was probably because I did high school science and I kind of had some access to it…I didn't really feel that it was a disciplinary thing, I kind of understood that it was a cultural, social thing. (Sarah, Final interview)

In the final interview, Rachel and Monica both expressed that they had "definitely" learnt about NOS during the course. For example, Monica stated:

> Definitely, I think through the discussions and how we all had the same material and all the same bits of data and evidence and how we all had a different spin on the same thing and I think that really showed the aspect where it talks about how everyone interprets data differently and it's got to do with their background and experiences and things like that. (Monica, Final interview)

Both Rachel and Monica stated that they had not heard of NOS in the initial interview.

These trends suggest a relationship between participants' perceived previous knowledge about NOS, and the possible development of their views of NOS. The two participants (Rachel and Monica) who did not show confidence in their pre-existing views of NOS exhibited more substantial development in their views of the examined NOS aspects, relative to the other participants. David expressed that he had not learnt anything new about NOS in the course and did not exhibit any substantial development in his views. Both Tom and Sarah expressed that they previously knew a lot about NOS, although at the end of the study but did state that they had learned some new ideas. These participants exhibited some development in their views of many of the examined NOS aspects, although this development was relatively less substantial than the development exhibited by Rachel and Monica.

6.5.3 Recognition of the importance or usefulness of NOS

Participants provided some interesting responses in the final interview regarding whether they enjoyed learning about NOS, and the usefulness of learning about NOS. All of the participants cited that they had enjoyed learning about NOS. Rachel and Monica both highlighted the difference between how science was taught in the course, and how they had been taught science at high school. Their responses indicated recognition of the limitations of teaching science as a body of knowledge. Monica stated:

> Well, I think when you learn the content, well I think back to biology in school, I used to take everything as it was real, the truth, fact and everyone believed in that, whereas now I read something and I'll think there's probably another side…. I think it's important that the students realise then that what we're doing and what I'm saying or what we're talking about, that there's different ways of viewing, not everyone sees it this way and encourage them that if you don't agree with this, that's fine. (Monica, Final interview)

Tom and Sarah referred to NOS as being useful to enable children to see the links between science and everyday life. David was not directly asked whether he found learning about NOS useful. Interestingly, David indicated that one of his most memorable moments in the course was the discussion of the socioscientific argumentation scenario concerning foetal tissue transplantation. In his response he expressed some initial confusion over the connection between the scenario and 'chemistry' noting:

> …I was a bit confused as to the connection between that and the chemistry you were doing. And, then again, because I was interested in both issues I thought, well who cares, and then as the unit progressed I could see what you were trying to do… To not only teach us chemistry but to teach us, I thought, that chemistry impacts on our lives, our everyday lives, and that is one way that it can impact, its not just simply a new drug has been discovered to do such and such, it has social implications as well. (David, Final interview)

This response indicates that David recognised the intention behind integrating NOS in the course, but did not necessarily ‘buy in’ to the usefulness of the approach himself.

Participants were also asked whether they felt the inclusion of both NOS and argumentation enhanced or detracted from the learning of the other course content. Rachel, Monica and Tom expressed that the inclusion of NOS and argumentation enhanced the learning of the other course content:

> I think in some ways its possibly even more important because going on the NOS being so uncertain, if we just taught content it’s going to be irrelevant, it’s like teaching us how to learn ourselves… (Rachel, Final interview)

David and Sarah provided some interesting responses to this question. David stated:

> Didn’t take away from it, pause, I don’t know whether it enhanced it for me, but I learnt a lot. And I liked what I learnt. So, I suppose it put a different slant on science for me, because I thought science was basically what you did at high school, and that those deep and meaningful discussions that we had just made it more interesting and put a different slant on what could otherwise be a dry subject. (David, Final interview)

This comment indicates that David was not convinced of the importance or utility value of learning about NOS. It is important to note that when David was asked whether he would have enjoyed the course more with or without the inclusion of NOS and argumentation, he commented:

> Oh, definitely not. I would much prefer the way we did it. If you would have done the chalk and talk on atoms and all that it would have been more difficult for you and less enjoyable for us. (David, Final interview)

Thus, although he enjoyed learning about NOS, he did not fully recognise the importance or utility value of learning about NOS, and simply indicated that it was an enjoyable teaching approach used to ensure that the class was not bored with traditional ‘chalk and talk’ teaching approaches. On the other hand, Sarah stated that she felt that learning about NOS and argumentation enhanced the learning of the other course content:

> Um, NOS, yes that did enhance it because chemistry is kind of very technical and obscure in some ways, so it did make it more relevant when you can sort of talk about embryos and that kind of thing because it is influenced by our perspectives, it is cultural and its developed this way, so learning about the NOS and then making it more accessible for kids…so that was a good slant on chemistry. Argumentation, yeah, it was also good too because it ties in with the NOS really ‘cause it’s developed by human discussion and debate and that kind of thing, so it was kind of reinforcing the NOS and chemistry. (Sarah, Final interview)

Interestingly, when asked whether she would have enjoyed the course more or less with or without the inclusion of NOS and argumentation, Sarah stated “probably less because I think you do need to have it in there somewhere” (Final interview). Thus, although Sarah recognised the importance or utility value of learning about NOS, she indicated it was something she had to tolerate, rather than fully enjoy. She expressed that she would have preferred to learn about NOS and argumentation throughout her science courses at university, not just encounter them in one of her final courses:

> It would have been good if we had more of the NOS earlier because we did a life and living unit before this one, and also in just general curriculum science... It didn't really give the context that science is, it's everywhere and you can tap into it and learn from it in everyday life. So it would have been good if that kind of perspective of science was shown a little bit earlier. (Sarah, Final interview)

These trends suggest a relationship between an appreciation of the importance and utility value of learning about NOS, and the possible development of participants' views of NOS. Rachel, Monica, Tom, and to a lesser degree, Sarah, all recognised the usefulness of learning about NOS in the course. These participants expressed that NOS ideas enhanced their learning of the other course content. Conversely, although David expressed he had enjoyed learning about NOS in the course, he did not recognise its importance or utility value, and viewed the inclusion of NOS as a novel teaching approach, designed to make learning science more interesting.

6.6 Summary

The purpose of this chapter was to explore the change (or lack thereof) in participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. All of the participants expressed naïve and/or limited views of six or more of the eight examined NOS aspects at the commencement of the study. Many positive changes were evident at the end of the intervention with four of the five participants (Rachel, Monica, Tom and Sarah) expressing partially informed and/or informed views of five or more of the eight examined NOS aspects. These four participants experienced development in at least five of the eight examined aspects. David's largely naïve and/or limited views of the examined NOS aspects remained relatively unchanged at the conclusion of the intervention. Participants' views of the subjective and theory-laden NOS, the social and cultural NOS, and the creative and imaginative NOS, were the most developed aspects of NOS assessed in this study. Conversely, participants' views of theories and laws were the least developed aspect of NOS assessed in this study.

An analysis and comparison of participants' VNOS-C profiles and final interview transcripts pertaining to NOS, indicated three important trends in the data. First, an examination of participants' definitions of NOS expressed in the final interview corresponded positively to the aspects of NOS that developed most substantially in the VNOS-C. Second, participants' perceived previous knowledge about NOS appeared to influence the development of their NOS views; and third, a lack of appreciation of the importance and utility value of learning about NOS appeared to influence the development of participants' views of NOS. These trends will be critically analysed in Chapter 8.

In conclusion, findings from this chapter provided evidence to address the first research question:

1a. *What are preservice primary teachers' initial views of the examined aspects of NOS?*

1b. *Do their views of these aspects of NOS change over the course of the intervention?*

Participants expressed largely naïve and/or limited views of the majority of the examined NOS aspects at the commencement of the study. Four of the five participants' views of the majority of the examined NOS aspects changed over the course of the intervention, to partially informed and/or informed views of NOS.

The following chapter will address the second research question by providing an analysis of the influence of the course components on the development of participants' views of the examined NOS aspects.

CHAPTER 7 – RESULTS – COURSE COMPONENTS

7.1 Introduction

This chapter will provide a comprehensive analysis of the influence of the six course components implemented during the study, on participants' views of the examined NOS aspects. Findings from this analysis will provide evidence to address the second research question:

> *What is the influence of the various course components implemented during the study, on preservice primary teachers' views of the examined aspects of NOS?*

The purpose of this chapter is to evaluate the influence of the course components on participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. The chapter commences with an examination of the influence of explicit NOS instruction on participants' views of NOS, and is followed by an examination of the influence of explicit argumentation instruction on participants' NOS views. A detailed assessment of the influence of the argumentation scenarios on participants' views of NOS will be followed by a consideration of the influence of the global warming task on these views. The influence of the superconductors survey on participants' NOS views will then be outlined, followed by an assessment of the influence of the laboratory project on participants' NOS views. The chapter will conclude with a summary of the influence of each course component on participants' views of NOS.

This chapter will present both empirical data derived from the implementation of the various course components, and transcripts of participants' perceptions of the intervention, sourced from the final interview. It is important to note that participants' perceptions are self-reported, and their role in this study is to provide possible explanations for trends identified through the data analysis process. Analysis of these self reports provides key information to aid in assessing the influence of the various course components on participants' views of the assessed NOS aspects.

In addition, as this was an exploratory study that did not utilise a comparison group (i.e., a group that experienced the science content course without one or more of the six course components implemented in this study), causal claims about the *relative* effectiveness of one course component over another are not able to be made. Findings presented in this chapter will highlight information pertaining to each course component, but similarly to Schwartz et al. (2004), the requirement of individual course components on the possible development of participants' NOS views is not able to be determined as participants experienced all six components within the one science content course. The question of how these components interacted with each other remains an open question.

The six course components implemented during the study to aid in the development of participants' views of NOS were described in detail in Section

5.6.3. These components were (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project.

7.2 Explicit NOS instruction

Aspects of NOS were explicitly taught during classroom teaching sessions, with the eight assessed NOS aspects (empirical NOS, methods of science, theories and laws, tentative NOS, inference and theoretical entities, subjective and theory-laden NOS, social and cultural NOS, and creative and imaginative NOS) being emphasised over the course of the main intervention. These NOS aspects were embedded within the science content of the course to enable contextualised NOS instruction to occur (refer to Section 5.6.3.1 for more details). Each of the examined NOS aspects were given approximately equal class time in duration, and these explicit NOS sessions generally encompassed 15-30 minutes of each of the 3-hour sessions.

Participants' final interview transcripts were searched for any references to explicit NOS instructional activities. Only two specific references to explicit NOS instructional activities were found, although three of the participants referred to the classroom 'discussions' when they were asked to recall any specific instances of NOS in the course. Rachel expressed that she felt NOS ideas were not directly taught in the course, and that the class discussions and questioning aided her in developing her understandings of NOS:

> ...the way we'd have discussions about things, and come to realise that not everything is as straight cut as you think it is, especially coming out of high school

> and you’re just told this is how it is, the questioning through the lessons helped me to understand that a bit better. (Rachel, Final interview)

This view was supported by another comment she made when she was asked to recall any specific instances of NOS in the course:

> I think it was more just a theme, and it didn’t just come up in one big block, it came through everything we talked about. (Rachel, Final interview)

Monica and Sarah both referred to the class discussions as aiding their understandings of NOS. Sarah made explicit mention of theories and laws in her final interview response:

> I think it was good to discuss it with other people as well than just sort of discovering science so that was cool. But, it was a good context to learn about the laws and theories of things in chemistry. (Sarah, Final interview)

Monica and David both cited explicit NOS instructional activities when asked whether they could recall any specific aspects or instances of NOS during the course. Monica referred to an explicit NOS instructional activity which highlighted the subjective and theory-laden NOS and commented:

> … Because you think that because you’re seeing something happening, the observation, and you draw conclusions about why. (Monica, Final interview)

David recalled an explicit NOS instructional activity which focused on the development of the periodic table:

> Things that stood out in my mind, I don't know if this answers your question, is when you started quoting dates when certain chemicals were discovered. I didn't realise that scientists back in the 1800s could deduce that. I also got a big surprise when you told us that, I think you said that they knew that there was some sort of a void there that had to be filled, I don't know if you said mathematically. (David, Final interview)

Thus, these findings provide evidence to suggest that the inclusion of explicit NOS instruction aided some of the participants' understandings of a couple of the examined NOS aspects, although references to specific explicit NOS instructional activities in participants' final interview responses were infrequently cited. Importantly, the inclusion of explicit NOS instruction is considered to be a necessary pre-requisite for developing informed understandings of NOS, to enable participants to familiarise themselves with descriptions of the various aspects of NOS, and to enable them to compare these descriptions with their pre-existing views of NOS.

7.3 Explicit argumentation instruction

Argumentation instruction was explicitly implemented during classroom teaching sessions by incorporating teaching materials developed from the Ideas, Evidence and Argument in Science Project 'IDEAS' (Osborne et al., 2004). Participants were introduced to various aspects of argumentation such as the importance of empirical evidence, evaluating evidence, structure of a 'good' argument,

argument prompts, counterarguments, qualifiers, writing frames, rebuttals, Toulmin's model of argumentation, and evaluating the quality of arguments (refer to Section 5.6.3.2 for more details). Explicit argumentation instruction was conducted over five classroom sessions, and each of these argumentation sessions were generally 30 minutes in duration, and were coupled with the introduction of a scientific or socioscientific argumentation scenario (refer to Section 7.4 for more details).

Participants' final interview transcripts were searched for any references to explicit argumentation instructional activities. Participants only cited components of explicit argumentation instruction when asked whether they could recall any specific instances or aspects of argumentation during the course. For example, David referred to an instructional sheet on how to construct an argument:

> When you gave us that A4 about how to construct an argument, I tried to use that in my first assignment (global warming essay) and I learnt that it has to be structured, and it has to follow certain steps so that it progresses through to a conclusion. (David, Final interview)

Monica cited warrants and qualifiers in her response, and Tom referred to Toulmin's model of argumentation. Sarah recalled the components of an argument, and the framework for evaluating arguments, in response to this question:

> I remember all the overheads and handouts and things. There was the one that had all the components of an argument, data, evidence... There were also the five

> guiding questions that you use to construct an argument and debunk someone else's argument. (Sarah, Final interview)

In summary, the infrequent citing of explicit argumentation instruction by participants was not unexpected as this course component was primarily designed and implemented in the study with the aim of familiarising participants with descriptions of the various components of an argument, and to facilitate participants' engagement in the argumentative aspects of the other course components (e.g., argumentation scenarios, global warming task, superconductors survey, and laboratory project).

7.4 Argumentation scenarios

Participants engaged in a series of five argumentation scenarios during the main intervention of the study. Two of these argumentation scenarios were situated in scientific contexts, and three of the scenarios were situated in socioscientific contexts (refer to Section 5.6.3.3 for more details). These argumentation scenarios were generally implemented after explicit argumentation sessions, and were introduced at contextually relevant sections of the class session. Each argumentation scenario was generally 45-60 minutes in duration.

Two sources of data were examined to assess the influence of the argumentation scenarios on participants' views of NOS. First, transcripts from audio-taped class sessions were searched for explicit references to NOS aspects as participants engaged in the argumentation scenarios. Second, participants' final interview transcripts were searched for any references to the argumentation scenarios.

Findings from each of these data sources will be presented in the following sub-sections.

7.4.1 Explicit references to NOS during argumentation scenarios

Transcripts of participants’ oral discourse as they engaged in classroom argumentation scenarios were examined for any explicit references to aspects of NOS. There were no explicit references to NOS in participants’ oral discourse in either of the scientific argumentation scenarios by any of the participants. There were also no explicit references to NOS in participants’ oral discourse in any of the three socioscientific argumentation scenarios by either Rachel or Monica. Tom and David each made a single explicit reference to NOS in their oral discourse during the socioscientific argumentation scenarios, and Sarah made two explicit references to NOS in her oral discourse during these scenarios. These findings suggest that participants’ views of NOS were generally not reflected in their argumentative discourse in either scientific or socioscientific contexts in this study.

7.4.2 References to argumentation scenarios in the final interview

Participants’ final interview transcripts were searched for any references to the argumentation scenarios. An analysis of participants’ final interview responses that pertain to argumentation scenarios indicated three important findings: (a) influence of argumentation scenarios as a context for learning about NOS, (b) factors that limit engagement in oral argumentation, and (c) recognition of the importance or usefulness of argumentation. These findings will be discussed in the following sub-sections.

7.4.2.1 Influence of argumentation scenarios as a context for learning about NOS

The argumentation scenarios were cited as one of the most enjoyable aspects of the course by Tom, David and Monica. Three of the participants (Rachel, David and Sarah) specifically referred to the argumentation scenarios when asked whether they could recall any specific aspects or instances of NOS during the course. Rachel referred to the socioscientific argumentation scenarios in her response:

> Um, probably the ethics behind everything, it's not just clear cut, we can't make a decision based on it can be done so we will do it, there are ethical issues involved in it and they have to be considered. (Rachel, Final interview)

David also referred to a socioscientific scenario in his response. Sarah referred to the argumentation scenarios in general, stressing the subjective and theory-laden NOS in her response:

> I think all of the little scenarios about how it was presented as 'this is a problem that's open to debate,' it's open for everyone to provide their perspectives on, that science is something that everyone's got opinions about, debate and discuss. (Sarah, Final interview)

These findings indicate that the argumentation scenarios provided a context for learning about aspects of NOS for some participants.

7.4.2.2 Factors that limit engagement in oral argumentation

Although Tom, David and Monica cited that engaging in the argumentation scenarios was one of the most enjoyable aspects of the course, Rachel and Sarah stated that they had not enjoyed engaging in the argumentation scenarios. Sarah stated:

> I wasn't much keen on the discussion in class because it generally got controlled by a few people, but that was probably more class dynamics than the unit itself…the mature age students generally dominated the discussion. (Sarah, Final interview)

This comment indicates that Sarah did not take issue with the nature of the argumentation scenarios, but instead disliked participating in oral argumentation in the classroom. She expressed a lack of confidence in her perceived scientific knowledge in comparison with Tom, and stated that she often felt intimidated by his comments "obviously his opinion was more correct than ours (laughs)…" (Final interview). Rachel also expressed some discomfort with engaging in the argumentation scenarios. When she was asked whether she had learnt about argumentation during the course she expressed that she had witnessed a lot of argumentation, but had not participated in it as much as she could have. She stated:

> I felt that at the beginning when I first started I thought 'I can learn this, I can start to become more argumentative, as soon as I can get more knowledge, but I found the more I was there, and I began to see everyone else and what content background they had, I felt less sure of myself, and so I wouldn't want to. (Rachel, Final interview)

Similarly to Sarah, Rachel expressed a lack of confidence in her ability to engage in oral argumentation due to a perceived lack of sufficient scientific content knowledge. Rachel also expressed that she did not feel she possessed sufficient skills of argumentation to participate in the scenarios:

> I think it's something you have to gradually learn over a period of time and practice with because you did teach us how to go about it, and how to unpack an argument and how to write one and all that sort of thing. I think I could probably write one to a satisfactory level but it's a matter of actually putting my point of view across in an oral situation, it's quite different. (Rachel, Final interview)

Other participants referred to the influence of group dynamics on engagement in argumentation in the scenarios. For example, although Monica stated that she felt comfortable discussing concepts and ideas, she did note that she disliked some of the other class members' personalities. Tom stated that he also enjoyed the argumentation scenarios, but expressed that he had found it difficult to talk to some of the younger students.

These findings suggest that factors such as perceived science content knowledge, skills of argumentation, and group dynamics may influence participants' engagement in oral argumentation, and therefore impact on their participation in the argumentation scenarios.

7.4.2.3 Recognition of the importance or usefulness of argumentation

As stated above, Rachel expressed that she did not enjoy engaging in oral argumentation, although she did express that she had enjoyed learning about argumentation in the course. When she was asked whether she thought argumentation was useful to teaching or learning science, or to herself personally, Rachel expressed uncertainty:

> I don't know. I always see it as more an academic thing. It seems important now for my academics but I'm still not sure how to relate it later on, I guess teaching you should teach how to actually have a proper argument otherwise what's the point of just rattling on and not knowing what you're talking about and I understand how that's important. Right now, I can only see in the short term of how it's important. (Rachel, Final interview)

Although Rachel recognised the importance of using evidence in arguments, she expressed uncertainty as to whether she would consider using argument in her science classes:

> I don't know, I'm more of a trying to get the kids to develop it themselves…like using questioning to get them to actually start doing it themselves, rather than me arguing at them. But I can see how it is relevant in that way, by getting them to start providing evidence for what they're saying, that's really important. (Rachel, Final interview)

Sarah also expressed that she did not enjoy engaging in oral argumentation. Similarly to Rachel, she expressed that she had enjoyed learning about argumentation, but commented that she found it unusual to learn about it in a science course:

> Yes, although I feel that it's more of an English kind of realm, like debating, more of an English, drama kind of slant on science. It was interesting to encounter it in science, because obviously that's how knowledge is developed in different fields and that kind of thing, debating, but um (pause) I wasn't really sure of the relevance to this subject. So, I did learn about it. (Sarah, Final interview)

Sarah clarified that she did see the relevance of argumentation towards the end of the course, but stated that there was a lot of time devoted to it in the course:

> …I did think there was a rather large emphasis on it. We could have probably covered it in one lesson – this is how knowledge is developed, here are some examples, and then, like 'cause we kept applying it, most lessons we would discuss a case study or discussing past argumentation, and I thought that time could have been spent more on the chemistry kind of side of the unit. (Sarah, Final interview)

The other three participants also expressed they had enjoyed learning about argumentation in the course, although these participants expressed positive views of the usefulness of argumentation to teaching and learning science. For example, David stated:

> …When you gave us that A4 about how to construct an argument, I tried to use that in my first assignment and I did learn that you can't just, even having a polite argument, so writing that assignment that we did for you, that it has to be structured, and it has to follow certain steps so that it progresses through to a conclusion. It made me realise that you can't just stand in there like two thugs at a bar, just throwing criticism at you, I suppose it taught me a more intellectual, intelligent way of doing it. (David, Final interview)

Monica stated that she felt that argumentation had relevance to all areas of life, including post-school experiences. She expressed that argumentation was useful to teaching or learning science as it allowed people to "… see how others put their argument forward. You can analyse it better by seeing how they set theirs up" (Final interview). She also expressed that she thought argumentation was included in the course to enable participants to engage in the global warming task:

> Because we were dealing with a topic that has such different opinions, and so by putting our opinion forward we had to use a good argument and we needed a good structure for that. (Monica, Final interview)

These trends suggest a relationship between an appreciation of the importance and usefulness of argumentation, and participants' engagement in argumentative activities such as the argumentation scenarios.

7.4.3 Summary

Two sources of data were examined to assess the influence of the argumentation scenarios on participants' views of NOS. Transcripts from audio-taped class sessions were searched for explicit references to NOS aspects in participants' oral discourse as they engaged in the argumentation scenarios. Findings suggested that participants' views of NOS were generally not reflected in their argumentative discourse in either scientific or socioscientific contexts.

Participants' final interview transcripts were searched for any explicit references to the argumentation scenarios. An analysis of participants' final interview responses that pertain to argumentation scenarios indicated three important findings. First, many participants specifically referred to the argumentation scenarios as providing examples of learning about NOS during the course. These findings indicate that the argumentation scenarios provided a context for learning about aspects of NOS for these participants. Second, factors such as perceived science content knowledge, skills of argumentation, and group dynamics may influence participants' engagement in oral argumentation, and therefore impact on their participation in the argumentation scenarios. Third, a lack of appreciation of the importance and usefulness of argumentation may hinder participants' engagement in argumentative activities such as the argumentation scenarios.

In summary, although some of the participants explicitly cited the argumentation scenarios as a context for learning about NOS, very few explicit references to NOS aspects were reflected in their argumentative discourse whilst engaged in the scenarios. Importantly, engaging in oral argumentation presented some challenges for the participants, which may have hindered their participation in the scenarios. Implications of these findings will be discussed in Chapter 8.

7.5 Global warming task

The global warming task consisted of two inter-related parts: (a) the global warming survey, and (b) the global warming essay (refer to Section 5.6.3.4 for more details). Participants presented their oral responses to the global warming survey during Weeks 9 and 10 of the main intervention, and submitted their written global warming essays during the post-intervention phase of the study. This section will outline findings from each of these tasks separately, and conclude with a summary of the main results and trends.

7.5.1 Global warming survey

The global warming survey was utilised in this study as an introduction to the global warming essay. The survey provided opportunities for participants to apply their understandings of specific aspects of NOS to their reasoning in a socioscientific context. Two of the five questions on the survey assessed participants' views of the social and cultural NOS (Question 2), and the subjective and theory-laden NOS (Question 3). Participants' responses to these questions were examined to enable an assessment of their views of each of these aspects to be determined. In addition, their views of these aspects of NOS as expressed in the global warming survey (socioscientific context) were compared to their views of these aspects of NOS expressed in the VNOS-C to ascertain whether participants expressed similar views of these NOS aspects across differing contexts.

7.5.1.1 Social and cultural influences on the development of scientific ideas

This question focused on the influence of social factors on the development of scientific ideas and concepts. Rachel expressed an informed view of this aspect that recognised the influence of social and cultural factors on the practices of science:

> That is definitely true, societal factors influence everything, societal factors influence my point of view today, it's influenced everyone here's point of view of what side they eventually chose. Yes, they backed it up with data but what you eventually chose was because of what you really believed. But definitely in science, especially with that first argument, the data they collected would have been influenced by who was funding them, and it also would have been influenced by

> what the people who were funding them wanted to hear. The same goes for the environmental side, they will want to find evidence which proves that we are causing damage... (Rachel, GW survey, Q2)

This view aligns with her informed view of the social and cultural NOS expressed on the post-intervention VNOS-C:

> I believe that science reflects social and cultural values because I believe that all human activity is bound to the values and beliefs an individual or group of people acquire through lived experiences… (Rachel, VNOS, Q9)

Monica, Tom and Sarah all expressed partially informed views of the social and cultural NOS that recognised the influence of social and cultural factors on what scientists investigate. For example, Sarah stated:

> Yes, the myth side is influenced by economic and social factors, so their saying it's going to be too expensive, it will upset the economy. With an upset economy everything else is affected. The crisis side are influenced by environmental and social factors, by arguing that animal and plant life and human populations are going to be significantly affected. (Sarah, GW survey, Q2)

Monica, Tom and Sarah's views of this aspect were aligned with their partially informed views of the social and cultural NOS expressed on the post-intervention VNOS-C. For example, Tom expressed:

> ...there is no such thing as pure science for the science, but science research is always carried out with a financial or social dividend in mind. (Tom, VNOS, Q9)

David expressed a limited view of the social and cultural NOS on the global warming survey. Although he recognised that social and cultural factors influence scientific ideas and practices, his response indicated that these influences are negative:

> The environmentalists use a subtle, but doomsday type of approach. They paint this bad picture and they make you feel guilty about it. It’s a threat to humans, animals, plant life and the whole world in general... (David, GW survey, Q2)

David’s view of this aspect aligns with his limited view of the social and cultural NOS expressed on the post-intervention VNOS-C:

> …If your culture is strong in social and religious values, your view on a scientific phenomenon may be biased. If you do not have strong social, cultural or religious convictions then your science may be more ‘encompassing’ …and by that I mean, sort of neutral. (David, VNOS, Q9)

7.5.1.2 The subjective and theory-laden nature of scientific ideas

This question was concerned with the subjective and theory-laden NOS, and asked participants to consider how different groups of scientists could interpret the same data set in different ways, and in turn draw different conclusions.

Rachel, Monica and Tom displayed informed views of this aspect, recognising that a scientist's background and experiences influence their interpretation of empirical evidence. For example:

> Even though both articles have the same material, for instance they both claim that the Earth's temperature has risen by 0.6 degrees C over the past decade, they have different conclusions as they interpret the data differently. An example of this is that the first group believes that the rise in temperature in part of the world's natural climate change, whereas the other side interpret this change as the direct result of burning fossil fuels and the increase in carbon dioxide. As previously discussed both groups have numerous societal factor influencing their conclusions on global warming. (Monica, GW survey, Q3)

> That's because we've got societal factors, you've also got factors such as the way people interpret mathematical results. 'Cause after all, data is just data, but knowledge comes from the way you interpret the data, the stats, and each person has a different upbringing, a different reason why they're interpreting the data, after all if you're being funded by a government that says we don't want to know about the crisis then you're going to be led toward that… (Tom, GW survey, Q3)

These views align with their views of the subjective and theory-laden NOS expressed on the post-intervention VNOS-C (although Tom expressed partially informed views of this aspect on the VNOS-C):

> …ah, I think it's more their background…in the background they've been brought up to believe, if they're more of a volcanologist leaning or astrological leaning, I think that has a lot to influence, and themselves what they've personally

> experienced, if they've gone out and seen volcanic layers, debris they'd be more tending to believe that way whereas if they've gone out and been on more impact sites and checked… they'd probably be more… (Tom, VNOS, Q8)

David was the only participant who expressed a limited view of this aspect, which focused on a lack of conclusive data to solve the problem:

> In my opinion, it is mainly for emotive reasons. Griffin, who is supporting the environmentalists, when you read his book, everything about what he writes, you can tell he's an environmentalist, his slant on everything is environmental. Singer on the other hand, the British physicist, he doesn't make a counter-claim about being an environmentalist, he just doesn't make any reference to it. He seems to be more open view. And the reasons why these different conclusions, is that no-one, in my opinion, can present an air tight argument that is conclusive for either argument… So long as there are people out there doubting the data there will be contrary viewpoints. (David, GW survey, Q3)

David's view of this aspect aligns with his limited view of the subjective and theory-laden NOS expressed on the post-intervention VNOS-C:

> I think conditions on earth would have been very similar regardless of which phenomena happened. Facts about the issue are few and vague allowing human opinion and emotion to come into play… (David, VNOS, Q8)

7.5.1.3 Summary

The global warming survey provided opportunities for participants to apply their understandings of specific aspects of NOS to their reasoning in a socioscientific context. Four of the participants (Rachel, Monica, Tom, and Sarah) expressed partially informed or informed views of the two examined NOS aspects (social and cultural NOS, and subjective and theory-laden NOS) on the survey, and one participant (David) expressed limited views of the two examined NOS aspects on the survey. All five of the participants' views of the examined aspects of NOS aligned with their VNOS-C responses. These findings suggest that participants' views of the social and cultural NOS, and the subjective and theory-laden NOS expressed in the VNOS-C, are similar to their views of NOS expressed in the global warming survey (socioscientific context).

7.5.2 Global warming essay

The global warming essay was implemented in the study to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in a socioscientific context, and also apply their understandings of NOS to their reasoning about the task. Participants' global warming essays were searched for explicit references to NOS aspects, and evidence of engagement in argumentation. Participants' final interview transcripts were also searched for references to the global warming task.

Engagement in argumentation was evident throughout the participants' global warming essays. Participants utilised various aspects of argumentation, such as data, claims, warrants, backings, rebuttals and qualifiers in their essays. References to aspects of NOS were prevalent throughout the participants' global warming essays. The most commonly cited aspects were the subjective and theory-laden NOS, the empirical NOS, and the social and cultural NOS. A couple of references were cited for the well supported nature of scientific theories, and the tentative NOS.

References to the subjective and theory-laden NOS were evident in all five of the participants' essays. For example:

> Clearly there are differing perspectives on all these predictions as the data we have is open to interpretation and extrapolation in many ways, depending on the perspective of the scientists. These predictions in turn inform or reinforce people's views of global warming and have a significant effect upon the courses of action theorists recommend. (Sarah, GW essay, p. 7)

> No human endeavour, even that of science, is isolated from personal biases, beliefs and interpretation. This is evident in the use of the increase of temperatures by 0.5 – 0.8 C from both arguments but with different emphasis on the repercussions of this data. These personal beliefs are also evident in the priority of importance given to different elements of the global warming issue… (Rachel, GW essay, pp. 10-11)

References to the empirical NOS were also common and evident throughout all five participants' essays. For example:

> As well as this, several of this side's arguments are based on emotive beliefs and unconfirmed evidence…Where as, 'The Against' side provides validated and reviewed research to back up their claims… (Monica, GW essay, p. 8)

> While there are compelling data and claims from both side of global warming debate, most of the data that theorist present is either unsubstantiated or unreliable. (Sarah, GW essay, p. 8)

Numerous references to the social and cultural NOS occurred throughout all participants' essays. For example:

> …Both arguments are supported by scientific evidence (often the one source of evidence) being interpreted by scientists who are employed/supported by lobby groups or by elements with a vested interest in the debate (Governments, multinationals, oil companies, Greenpeace, Planet Ark, etc.). (Tom, GW essay, p. 3)

Explicit references to other NOS aspects were less prevalent. For example, Rachel and Sarah made reference to the well-supported nature of scientific theories "For a scientific theory to be worthy of merit it must provide valid and authentic evidence to support it" (Sarah, GW essay, pp. 10-11). References to the tentative NOS were evident in comments made by Monica, David and Sarah. For example:

> Due to the uncertainties that still remain about global warming, it would be unwise to act as if we do? Ultimately, we have to use our best judgment guided by the current state of science to determine what the most appropriate response to global warming should be. (Monica, GW essay, p. 8)

Some participants made reference to the essay in the final interview, as one of the enjoyable aspects of the course. Importantly, all of the participants referred to the above cited aspects of NOS when they were asked to define NOS during the final interview, suggesting that the global warming task highlighted the application of specific NOS aspects, such as the social and cultural NOS, and the subjective and theory-laden NOS.

These findings suggest that the global warming essay provided an effective context to enable participants to apply their views and understandings of many aspects of NOS to their reasoning in the task.

7.5.3 Summary

The global warming task enabled participants to apply their understandings of aspects of NOS to their reasoning in a socioscientific context. Their views of some aspects of NOS expressed in the global warming survey aligned with their expressed views of these aspects in the VNOS-C, providing evidence to suggest that their views of NOS expressed in the VNOS-C are similar to those expressed in the global warming survey. Numerous references to many of the examined aspects of NOS were evident throughout participants' global warming essays, suggesting that the global warming task highlighted the application of specific NOS aspects, such as the social and cultural NOS, and the subjective and theory-laden NOS; and provided an effective context to enable participants' to apply their views and understandings of many aspects of NOS to their reasoning in the task.

7.6 Superconductors survey

The superconductors survey was utilised in this study to provide opportunities for participants to apply their understandings of aspects of NOS to their reasoning in a scientific context (refer to Section 5.6.3.5 for more details). Participants provided written responses to the survey during the pre- and post-intervention phases of the study, and also took part in follow up interviews to clarify and further probe their responses.

An assessment of participants' views of the examined NOS aspects (as assessed by the superconductors survey) at the commencement and conclusion of the study was conducted. Findings from this assessment enabled changes in participants' views of the examined aspects of NOS to be determined. In addition, participants' views of NOS as expressed in the superconductors survey (scientific context) were compared to their views of similar aspects of NOS expressed in the VNOS-C, to ascertain whether participants' expressed similar views of these NOS aspects across differing contexts. The empirical NOS and the subjective and theory-laden NOS were identified as similar aspects of NOS across both instruments. It is important to note that the use of different coding schemes across these two instruments limits a direct comparison of views of NOS, although it does allow an assessment of general trends in NOS views across contexts.

As detailed in Section 5.9.1.3, participants' responses to each of the three sections of the survey were coded as either 'data focused views,' 'model focused views,' or 'relativist focused views.' In this study, participants who exhibited predominantly data focused views across the three sections of the survey represented less desirable understandings of NOS. Conversely, participants who exhibited predominantly model focused or relativist focused views across the three sections of the survey represented more desirable understandings of NOS. Descriptions of each of these views of NOS were provided in Table 5.5, and are reproduced in this section for ease of reference.

Table 7.1 *Descriptions of epistemological views (Ryder & Leach 2000; Leach et al. 2000)*

Data focused views	Model focused views	Relativist focused views
Data focused views reflect a belief in the primacy of data. The processes of measurement and data collection are viewed as simply involving 'copying' from reality, and the process of drawing conclusions is a simple one of stating what happened in an experiment. Scientific knowledge claims are viewed as descriptions of the material world, and differences of interpretation can be resolved by collecting enough data of an appropriate form.	Model focused views recognise the importance of considering underlying models when interpreting data. Understands the distinction between models, predictions and data. Recognition that data treatment should be informed by underlying models, and that models are based on theoretical ideas and data collected through experimental measurements.	Relativist focused views reflect the view that there are limited grounds for assessing the truth of knowledge claims in science. Multiple interpretations of the same data are possible. Data interpretation is subjective and theory-laden, is influenced by factors such as a scientists' theoretical orientations, beliefs, previous knowledge, experiences and expectations. Appreciates the role of data as providing empirical evidence to support the chosen position.

The following sub-sections will outline findings from the pre- and post-intervention administrations of the survey. Participants' responses to the superconductors survey are summarised in Table 7.2.

Table 7.2 *Summary of participants' responses to the Superconductors survey*

	Rachel		Monica		Tom		David		Sarah	
Survey	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Part 1	IR	wRF	wDF	RF	DF	DF	DF	DF	DF	DF
Part 2	DF	wRF	DF	wRF	DF	DF	DF	DF	DF	DF
Part 3	DF	DF	IR	RF	DF	wRF	DF	DF	DF	wDF
Overall	**DF**	**wRF**	**DF**	**RF**	**DF**	**DF**	**DF**	**DF**	**DF**	**DF**

(DF) Data focused response
(RF) Relativist focused response
(IR) Invalid response
(wDF) Weakly data focused response
(wRF) Weakly relativist focused response

7.6.1 Pre-intervention survey

7.6.1.1 Part 1

Four of the participants (Monica, Tom, David and Sarah) expressed data focused responses to Part 1 of the survey. Tom and David selected a data focused closed stem that focused on the primacy of data:

> It is unclear which group has drawn the best line, but if enough data are collected it should be possible to decide between the two lines. (Part 1, Response D)

Monica and Sarah selected a relativist focused closed stem:

> Both interpretations are acceptable. It is not possible to find out which interpretation is better. (Part 1, Response E)

Follow up interviews conducted with Monica and Sarah indicated that their selection of this closed stem actually indicated a data focused view, as when they were asked to explain why they chose their written responses, their verbal responses indicated an underlying data focused view. For example, Sarah stated:

> Well they all fit within the data so…well basically like they confirm what's already been proven so they're not disproving what's wrong and they're only a little bit outside… (Sarah, Pre-Super, Part 1)

Rachel selected a model focused closed stem in response to Part 1 of the survey:

> It is unclear which group has drawn the best line. You can only decide which interpretation is better by looking at the details of the LIS and COAST models. (Part 1, Response C)

This response was later considered to be invalid as she did not provide any verbal or written explanation for this choice, and her response of 'not sure' regarding the model focused closed stem in Part 2 contradicts this selection.

7.6.1.2 Part 2

All of the participants expressed data focused responses to Part 2 of the survey. These assessments were made after considering participants' responses to all of the closed stem items in Part 2, and a consideration of the participant's choice of the most important course of action to pursue.

All of the participants agreed with one or both of the two closed stems which were aligned with a data focused view:

> Collect more data to prove beyond reasonable doubt which group is correct. (Part 2, Response C)
>
> Reduce the errors in the measurements in order to prove beyond reasonable doubt that the LIS or the COAST model gives the best interpretation. (Part 2, Response D)

Rachel and Monica expressed uncertainty, and David disagreed with the model focused closed stem:

> It will only be possible to decide what to do next by considering the models proposed by the LIS and COAST groups. (Part 2, Response E)

These responses imply a lack of understanding of the nature of ‘models,’ and the key role they play in the development of theoretical descriptions. Tom agreed with the model focused closed stem, and Sarah failed to respond to this item.

Monica and Tom both agreed with the relativist closed stem:

> The scientists should accept that there can be more than one interpretation of this data. There is no way of finding out which interpretation is the correct one. (Part 2, Response H)

Neither of these participants provided any verbal comments about this response. Rachel was uncertain about this response, David did not agree with the response, and Sarah did not respond to this item.

Rachel and Sarah both chose data focused closed stems (Rachel - Response C, Sarah – Response D) as the most important thing to do next. These selections are considered to be limited as they place a central emphasis on the 'quantity' rather than 'quality' of data. They also fail to consider the importance of the underlying ideas contained in the models, and their role in making decisions about the interpretations.

Tom chose the model focused closed stem (Response E), followed by a data focused closed stem (Response C) as the most important thing to do next. David chose a non-specific closed stem:

> The scientists should follow a different course of action. (Part 2, Response I)

He clarified his choice of this response in his follow up interview, stating:

> Both groups should re-do their testing under exactly the same conditions as it appears an anomaly is responsible for the different outcomes. The anomaly may in fact be a hidden vital clue in making a breakthrough in the research on superconductors. (David, Pre-Super, Part 2)

This comment indicates that David did not recognise that the different groups were all using the same data, and had developed different models to explain and support their theories. Monica expressed uncertainty as to what the most important thing to do next would be.

7.6.1.3 Part 3

Four of the five of the participants expressed data focused responses to Part 3 of the survey. Interestingly, only one of the participants (Rachel) selected a data focused closed stem in her written response to the survey:

> Use a computer to generate the best curved line through the data points. This is the best approach. (Part 3, TESME group)

She followed this selection with the comment:

> 'Cause it's the less biased I suppose if they just give it to a third party… (Rachel, Pre-Super, Part 3)

This response is considered to be limited as it assumes that the computer will be able to make an unbiased judgment about the data. Rachel failed to recognise the computer is simply part of the overall data interpretation process, not the end-stage, and that the models that underpin the theory have an influence on the data interpretation process.

Tom and Sarah both chose the relativist focused closed stem:

> There is no way of knowing which is the best way to join the data points. It is up to individual scientists to make up their own minds. (Part 3, ROMA group)

Closer analysis of Tom and Sarah's written survey comments, and interview data indicated that they both subscribed to a data focused view of this closed stem. For example, Tom followed his selection with the following written comment:

> I take this view as it takes into consideration personal errors and beliefs, from this you amalgamate ideas drawing upon a (vast) larger result pool and thus reducing the human element (error) factor. (Tom, Pre-Super, Part 3)

David expressed that he did not agree with any of the group responses and commented:

> As already stated, further research needs to be done into why the data is different from group to group. Only then can the research resume into superconductors. A reliable and consistent data collection system has to be developed first. (David, Pre-Super, Part 3)

This response confirms earlier expressed responses which indicated David did not recognise that the same data set was being interpreted in different ways. His continual emphasis on data lends support to his data focused tendencies. Monica did not respond to this part of the survey.

7.6.2 Post-intervention survey

All of the participants expressed overall data focused views during the pre-intervention administration of the superconductors survey. Two of the participants (Rachel and Monica) expressed overall relativist views during the post intervention administration of the survey, although it should be noted that

Rachel’s views were ‘weakly’ relativist. These two participants experienced a change in overall view from a broadly data focused to a broadly relativist focused view from the pre- to post-intervention administrations of the survey. The remaining participants (Tom, David and Sarah) expressed overall data focused views, with little change noted between the pre- and post-intervention administration of the survey.

7.6.2.1 Part 1

Rachel and Monica expressed views which were aligned with relativist focused views, and Tom, David and Sarah expressed data focused views, in Part 1 of the survey. Rachel and Monica both selected the relativist focused closed stem:

> Both interpretations are acceptable. It is not possible to find out which interpretation is better. (Part 1, Response E)

Rachel’s verbal explanation of her selection displays some weak data focused tendencies as it indicates that scientists only use interpretation when there is an absence of a correct answer, or a lack of data. The emphasis on ‘detaching’ oneself also indicates a belief in the primacy of data:

> I think because everything can be interpreted in a certain way, we’re probably not going to find out which one’s the best, because we’re probably not going to be able to detach ourselves, really and find out what the correct answer is, it’s so difficult… (Rachel, Post-Super, Part 1)

This view was mediated when she was asked about her view of the data focused closed stem:

> It is unclear which group has drawn the best line, but if enough data are collected it should be possible to decide between the two lines. (Part 1, Response D)

She expressed uncertainty about this closed stem, and did not focus on the collection of more data to solve the problem, stating:

> I don't know whether that would work because you could keep on collecting data all day and still probably come to two different conclusions. (Rachel, Post-Super, Part 1)

Tom, David and Sarah all expressed data focused views in response to Part 1 of the survey. Tom and David selected a data focused closed stem:

> It is unclear which group has drawn the best line, but if enough data are collected it should be possible to decide between the two lines. (Part 1, Response D)

For example, David's focus on the primacy of data was evident in his interview response:

> …If the data collected is accurate and unambiguous then you can only come to one conclusion. (David, Post-Super, Part 1)

Sarah selected the model focused closed stem:

> It is unclear which group has drawn the best line. You can only decide which interpretation is better by looking at the details of the LIS and COAST models. (Part 1, Response C)

This selection was considered to be invalid as Sarah stated in her follow up interview:

> …they're both valid, they've both got error margins, scientifically they're both correct. But obviously there must be an exact answer. (Sarah, Post-Super, Part 1)

This response indicates a belief in the primacy of data and is considered to be data focused.

7.6.2.2 Part 2

A similar pattern of overall responses were noted in Part 2 of the survey, where Rachel and Monica again expressed relativist focused views, and Tom, David, and Sarah expressed data focused views. These assessments were made after considering participants responses to all of the closed stem items in Part 2, and a consideration of the participants' choice of the most important course of action to pursue.

Although Rachel and Monica expressed overall relativist responses, they still both agreed with one of the data focused closed stems:

> Collect more data to prove beyond reasonable doubt which group is correct. (Part 2, Response C - Rachel)
>
> Reduce the errors in the measurements in order to prove beyond reasonable doubt that the LIS or the COAST model gives the best interpretation. (Part 2, Response D - Monica)

Neither Rachel nor Monica provided any written or verbal explanation of the selection of these data focused closed stems. Tom, David and Sarah agreed with both of the data focused closed stems.

Rachel and David expressed uncertainty about the model focused closed stem:

> It will only be possible to decide what to do next by considering the models proposed by the LIS and COAST groups. (Part 2, Response E)

Monica and Tom agreed with this closed stem but did not provide any written or verbal explanations to support their selection. Interestingly, Sarah indicated she did not agree with this closed stem, even though she chose a model focused closed stem in Part 1 of the survey (although this choice was invalidated due to her data focused comments during follow up interviews). This indicates a general lack of understanding of scientific models.

Rachel and Sarah agreed with the relativist focused closed stem:

> Both interpretations are acceptable. It is not possible to find out which interpretation is better. (Part 2, Response H)

Tom did not agreed with this closed stem stating “only through experimentation can we come to a better understanding” (Post-Super, Part 2). David also did not agree with the closed stem, again indicating a belief in the primacy of data in his response:

> I disagree with the first sentence…if its spot on, its spot on. You can’t say that ice freezes at between -2 and 2. You’ve got to say it freezes at exactly zero. So that’s the only interpretation there is… (David, Post-Super, Part 2)

Sarah expressed uncertainty about the closed stem, but did not provide any written or verbal clarification of her position.

Rachel and Monica both selected the relativist focused closed stem (Response H) as the most important thing to do next. Tom chose a non-specific closed stem as the most important thing to do next:

> Arrange for the LIS and COAST groups to meet together to decide between themselves which group has made an error. (Part 2, Response G)

This was an interesting selection as he had ‘not agreed’ with this closed stem in the written survey. He followed this selection with the comment:

> Have them meet, identify similarities and differences and then see if they can come up with a composite theory. Well if they couldn’t get any more data, which would be the ultimate thing, they need to come together, that way, you need to bring both

> sides cause obviously they're coming from two different viewpoints, well I think they're coming from two different viewpoints, and get them into a room and discuss similarities, what they thought of and what they didn't think of each side and then maybe come out with a collaborative theory. (Tom, Post-Super, Part 2)

This comment implies some understanding of developing a theory to explain the phenomena, although the emphasis of 'getting more data' again implies a belief in the primacy of data.

David and Sarah both chose the data focused closed stem (Response D) as the most important thing to do next. David commented:

> They should redo the experiment and reduce the error to nil or as near as possible to it. Then their data will be irrefutable. (David, Post-Super, Part 2)

When Sarah was asked how they could reduce the errors she stated:

> Well I'm assuming that they're making measurement errors or something so um tighten up the experiment…it would be really, really hard to do because obviously they've got it as precise as they can to start with. (Sarah, Post-Super, Part 2)

7.6.2.3 Part 3

In the final part of the survey, participants were asked to select the group closed stem which aligned most closely with their chosen course of action. Monica and Tom expressed relativist focused views, and Rachel, David, and Sarah expressed data focused views to this part of the survey.

Monica selected the relativist focused closed stem:

> There is no way of knowing which is the best way to join the data points. It is up to individual scientists to make up their own minds. (Part 3, ROMA group)

Her verbal response indicated an understanding of the subjective and theory-laden nature of scientific interpretation:

> I think there is no right or wrong. If both groups came up with nearly identical data results, then individual scientists will come up with their own idea where the line should go through. A computer generated line would do only what an individual scientist had programmed or taught it to go. As long as within the error margins, it can't be said that the line is wrong. (Monica, Post-Super, Part 3)

Tom also selected the relativist focused closed stem, but specified that he would only agree with this group "…if they use a line of best fit generated by standard deviations…If the data are as it stands then I support the ROMA group" (Post-Super, Part 3). When asked to clarify his position Tom stated:

> 'Cause you've obviously got different viewpoints coming together and each getting up and explaining it …bit like they did in the Manhattan Project, everything out on the plate, I think it's this, no I think it's this, and then you go through the reasonings. (Tom, Post-Super, Part 3)

Although this response is coded as relativist focused it is indicative of a weaker position as there is still some emphasis on 'data' in the original written response.

Sarah also selected the relativist focused closed stem, but unlike Monica and Tom, her post interview responses revealed a data focused tendency with regard to this part of the survey. She noted:

> …Physically speaking, there should be a correct answer, but if you've got the data points within the error margins, it's going to rely on everyone's circumstances, how they perform the experiment, how they choose to join it. While there is an absolute truth in there somewhere, it's going to be affected by the situation anyway…
> (Sarah, Post-Super, Part 3)

Sarah's emphasis on an 'absolute truth' aligns her response with data focused tendencies. Rachel and David both expressed data focused views. Rachel selected the data focused closed stem:

> Use a computer to generate the best curved line through the data points. This is the best approach. (Part 3, TESME group)

In her verbal explanation she commented:

> I agree with the TESME group because it is the only course of action which allows for an unbiased interpretation of the data. Human interpretation of data will always result in a biased result because of the opinions and experiences people bring to the situation. (Rachel, Post-Super, Part 3)

This comment implies a negative view of interpretation, and a focus on the primacy of data, although she did mediate this response by noting that computers required human input to operate, and are thus not completely unbiased. David also expressed a data focused view, although he did not select any of the group responses, and instead proposed:

> All groups should continue independent research minimising all chance of errors. Each group could then appraise the other groups testing method and collected data. Continual refinement of testing procedures should help minimise the room for errors. (David, Post-Super, Part 3)

His focus on reduction of errors implies a data focused tendencies.

7.6.3 Summary

All of the participants exhibited broadly data focused views of the three parts of the superconductors survey at the commencement of the study. Participants' responses typically focused on the primacy of data, and the reduction or elimination of experimental error to help solve the problem. Some participants selected model focused closed stems throughout the pre-intervention survey, but closer analysis of interview transcripts indicated the majority of participants failed to appreciate the nature of scientific models. In addition, participants' selection of relativist focused closed stems in the written survey were often unable to be validated as interview data indicated broadly data focused tendencies.

Two of the participants (Rachel and Monica) expressed overall relativist views during the post intervention administration of the survey, although it is important to note that Rachel's views were 'weakly' relativist. These two participants experienced a change in overall view from a broadly data focused view to a broadly relativist focused view from the pre- to post-intervention administrations of the survey. The remaining participants (Tom, David and Sarah) expressed overall data focused views with little change noted between the pre- and post-intervention administration of the survey. All five of the participants still failed to show an understanding of scientific models at the conclusion of the study.

7.6.4 Comparison of NOS views across assessments

Participants generally expressed limited views of the empirical and subjective and theory-laden NOS as assessed by the VNOS-C, at the commencement of the study (refer to Section 6.2 for more details). These views aligned closely with participants' data focused views expressed in the pre-intervention superconductors survey.

Rachel and Monica expressed partially informed and/or informed views of the empirical and subjective and theory-laden NOS as assessed by the VNOS-C, at the conclusion of the study. For example, Monica expressed an informed view of the subjective and theory-laden NOS in her post-intervention VNOS response:

> Different conclusions are possible from the same set of data, as different scientists have differing backgrounds, values, beliefs and training. These all contribute to the way they draw conclusions from data. (Monica, VNOS, Q8)

Rachel and Monica also expressed broadly relativist focused views in the post-intervention administration of the superconductors survey, indicating that their views of these examined NOS aspects were aligned across both instruments:

> I think there is no right or wrong. If both groups came up with nearly identical data results, then individual scientists will come up with their own idea where the line should go through. A computer generated line would do only what an individual scientist had programmed or taught it to go. As long as within the error margins, it can't be said that the line is wrong. (Monica, Post-Super, Part 3)

David's views of the examined NOS aspects were also aligned across both instruments, as he expressed limited views of the empirical and subjective and theory-laden NOS as assessed by the VNOS-C, and data focused views in the superconductors survey, during the post-intervention phase of the study. For example, David expressed a limited view of the subjective and theory-laden NOS in his post-intervention VNOS response:

> ...as far as I'm concerned if this occurs at 98 degrees Celsius, it's not 97 or 99, it is 98. So if your data are 100% accurate there is no room for speculation. (David, VNOS, Q10)

This limited view of the subjective and theory-laden NOS aligns with his data focused views expressed in the superconductors survey:

> …if its spot on, its spot on. You can’t say that ice freezes at between -2 and 2. You’ve got to say it freezes at exactly zero. So that’s the only interpretation there is… (David, Post-Super, Part 2)

Conversely, Tom and Sarah’s post-intervention views of the examined NOS aspects were not aligned across the two instruments. Although Tom expressed partially informed views of the empirical and subjective and theory-laden NOS as assessed by the VNOS-C, he expressed data focused views of these aspects in the superconductors survey. For example, he expressed a partially informed view of the subjective and theory-laden NOS in his post-intervention VNOS response to why scientists come to different conclusions from the same data:

> …ah, I think it’s more their background…in the background they’ve been brought up to believe, if they’re more of a volcanologist leaning or astrological leaning, I think that has a lot to influence, and themselves what they’ve personally experienced, if they’ve gone out and seen volcanic layers, debris they’d be more tending to believe that way whereas if they’ve gone out and been on more impact sites and checked… they’d probably be more… (Tom, VNOS, Q8)

This view was not aligned with his expressed views of NOS in the superconductors survey, which indicated a belief in the primacy of data:

> Have them meet, identify similarities and differences and then see if they can come up with a composite theory. Well if they couldn’t get any more data, which would be the ultimate thing, they need to come together... (Tom, Post-Super, Part 2)

Sarah also expressed data focused views of the subjective and theory-laden NOS in the superconductors survey that were not aligned with her partially informed view of the subjective and theory-laden NOS as assessed by the VNOS-C (although she did continue to express limited views of the empirical NOS as assessed by the VNOS-C).

7.6.5 Trends in the data

A consideration of the findings presented in the previous sub-section, and an examination of participants' initial and final interview transcripts will be discussed in this section. During the final interview, participants were asked whether they understood how to interpret the superconductors survey. Rachel, Monica and David expressed that they found the survey difficult to understand, in terms of interpreting the graphs, and understanding the wording of some of the closed stem responses. Rachel expressed that the research groups in the survey could be interpreting their data for "reasons other than science" but could not articulate what those reasons could be. Monica had not heard of superconductors before, nor had she encountered error bars, but had an idea that they indicated the range of measurements for each point. David also expressed difficulty in reading and interpreting the error bars.

On the other hand, Tom and Sarah expressed confidence in their abilities to interpret the survey, and were familiar with lines of best fit and error bars. They attributed this confidence to their background scientific knowledge (refer to Section 5.6.1.3 and Section 5.6.1.5 for more details). On numerous occasions during the study, Tom made reference to his extensive scientific knowledge. For example:

> …in a lot of circumstances I was listening and I was thinking maybe I need to dumb down what I know, because I'm thinking well, that's over the top, and of course, well from what I've done in the past, it is a little bit over the top. (Tom, Final interview)

Sarah also referred to her previous scientific knowledge during the study, and stated she had previously learnt about the science content covered in the course, and in previous science courses she had undertaken during her degree. For example, she referred to the science content covered in one of her previous courses during her initial interview:

> Pretty basic...I found it a little tedious 'cause, well it was just really basic to me, it was junior high school kind of stuff, I still remembered it, so other people I know got a lot out of it but I didn't. (Sarah, Initial interview)

These trends suggest a relationship between participants' previous scientific knowledge, and their expressed views of NOS in the superconductors survey. Findings from this study indicate that participants with previous scientific knowledge (Tom and Sarah) may express limited views of some aspects of NOS in scientific contexts (superconductors survey), whilst expressing partially informed views of the same NOS aspects in the VNOS-C. Participants without this background knowledge (Rachel, Monica and David) expressed similar views of the examined aspects of NOS across both instruments in this study.

Participants' final interview transcripts were also searched for explicit references to the superconductors survey. Sarah was the only participant who made reference to the superconductors survey when she was asked whether she could recall any specific aspects or instances of NOS during the course, highlighting the subjective and theory-laden NOS in her response:

> ...we did the sheets with the error bars on the graph and the interpretation of that; that is a clear marker for me about how different people interpret data differently, so that's something about the NOS... (Sarah, Final interview)

In summary, although the superconductors survey provided an effective context for participants to express and apply their understandings of aspects of NOS to their reasoning in a scientific context, only one participant cited the survey as an example of a NOS learning context in the study. Implications of these findings will be discussed in Chapter 8.

7.7 Laboratory project

The laboratory project was implemented in the study to provide opportunities for participants to develop and apply their skills and/or quality of argumentation in a scientific context, and also apply their understandings of NOS to their reasoning about the task. The project was designed to allow participants to research and test a range of chemicals to determine the most suitable chemical to solve the problem, thus providing a context for participants to engage in scientific argumentation by evaluating information, providing justifications for their choices, and offering rebuttals and counterarguments (refer to Section 5.6.3.6 for more details).

Participants' written laboratory reports were searched for explicit references to NOS aspects, and evidence of engagement in argumentation. Participants' final interview transcripts were also searched for references to the laboratory project. Results indicated that no engagement in argumentation was evident in participants' written laboratory reports. Although the project was designed with the underlying assumption that participants would research and test a variety of different chemicals, and provide an argument as to why one chemical was chosen over other chemicals, none of the participants' written reports provided a scientific argument to justify their choice of chemical.

There were no explicit references to aspects of NOS in any of the participants' written laboratory reports. None of the participants referred to the laboratory project as influencing their views of NOS, and no references to this course component were evident in any of the participants' responses during the final interview.

7.8 Summary

The purpose of this chapter was to evaluate the influence of the six course components on participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. The six course components implemented in the study were: (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project.

Findings from this chapter provided evidence to address the second research question:

What is the influence of the various course components implemented during the study, on preservice primary teachers' views of the examined aspects of NOS?

The inclusion of explicit NOS instruction aided some of the participants' understandings of a couple of the examined NOS aspects, although references to specific explicit NOS instructional activities in participants' final interview responses were infrequently cited. Importantly, the inclusion of explicit NOS instruction is considered to be a necessary pre-requisite for developing informed understandings of NOS, to enable participants to familiarise themselves with descriptions of the various aspects of NOS, and to enable them to compare these descriptions with their pre-existing views of NOS.

The infrequent citing of explicit argumentation instruction by participants was not unexpected as this course component was primarily designed and implemented in the study with the aim of familiarising participants with descriptions of the various components of an argument, and to facilitate participants' engagement in the argumentative aspects of the other course components (e.g., argumentation scenarios, global warming task, superconductors survey, and laboratory project).

Although some of the participants explicitly cited the argumentation scenarios as a context for learning about NOS, very few explicit references to NOS aspects were reflected in their argumentative discourse whilst engaged in the scenarios. Factors such as perceived science content knowledge, skills of argumentation, and group dynamics influenced some participants' engagement in oral argumentation, therefore impacting on their participation in the argumentation scenarios. In addition a lack of appreciation of the importance and usefulness of argumentation hindered some participants' engagement in the argumentation scenarios.

The global warming task enabled participants to apply their understandings of aspects of NOS to their reasoning in a socioscientific context. Participants' views of some aspects of NOS expressed in the global warming survey aligned with their expressed views of these aspects in the VNOS-C, providing evidence to suggest that views of NOS expressed in the VNOS-C are similar to those expressed in a socioscientific context (global warming task). Participants engaged in argumentation in their global warming essays. Numerous references to many of the examined aspects of NOS were evident throughout participants' global warming essays, suggesting that the global warming task highlighted the application of specific NOS aspects, and provided an effective context to enable participants to apply their views and understandings of many aspects of NOS to their reasoning in the task.

Although the superconductors survey provided an effective context for participants to express and apply their understandings of aspects of NOS to their reasoning in a scientific context, only one participant cited the survey as an example of a NOS learning context in the study. All of the participants exhibited broadly data focused views of the three parts of the superconductors survey at the commencement of the study. Two participants experienced a change in overall view from a broadly data focused view to a broadly relativist focused view at the end of the study, with the three remaining participants expressing little change in their pre- and post-intervention views. A comparison of participants' views of similar aspects of NOS across the superconductors survey and VNOS-C, indicated that factors such as previous scientific knowledge influenced participants' expressed views of NOS in scientific contexts.

There were no explicit references to aspects of NOS in any of the participants' written laboratory reports. None of the participants referred to the laboratory project as influencing their views of NOS, and no references to this course component were evident in any of the participants' responses during the final interview.

The following chapter will address the third research question by identifying and critically analysing the various contextual, task-specific, and personal factors that mediated the development of participants' views of the aspects of NOS examined in this study.

CHAPTER 8 – DISCUSSION

8.1 Introduction

This chapter will provide a critical analysis of the various contextual, task-specific, and personal factors mediating the development of participants' views of the examined NOS aspects. Findings from this analysis will provide evidence to address the third research question:

> *What factors mediated the development of preservice primary teachers' views of the examined aspects of NOS?*

The purpose of this chapter is to identify and critically examine the various factors that mediated the development of participants' views of the examined NOS aspects. The identified factors discussed in this chapter will include factors that directly mediated participants' views of NOS, and also factors that indirectly mediated participants' views of NOS by influencing their engagement in argumentation. Intuitively, a necessary pre-requisite for applying views of NOS to reasoning in scientific or socioscientific contexts, recognises that one must first be engaged in argumentation. If participants are not engaged in argumentation, then they have no opportunity to apply their views of NOS to their reasoning. A discussion of both direct and indirect influences on participants' NOS views will be presented in this chapter.

The chapter will commence with a critical examination of the influence of contextual factors on the development of participants' views of the examined NOS aspects. Task-specific factors will then be identified and critically examined, followed by a discussion of the influence of personal factors on the development of participants' NOS views. A summary of the various factors that mediated the development of participants' views of the examined NOS aspects in this study will conclude the chapter.

8.2 Contextual factors

A consideration of the results of the study that were analysed and presented in Chapter 7 identified two contextual factors that mediated the development of participants' views of the examined NOS aspects: (a) context of argumentation (scientific and socioscientific), and (b) mode of argumentation (oral and written). These factors will be considered in the following sub-sections.

8.2.1 Context of argumentation

Participants were engaged in argumentation in two contexts in this study, scientific and socioscientific. This section will discuss the influence of multiple epistemologies on participants' reasoning in scientific and socioscientific contexts, and will outline difficulties in engaging in argumentation in scientific contexts.

8.2.1.1 Multiple epistemologies

Findings from this study indicated that participants' expressed views of aspects of NOS in socioscientific contexts were aligned with their expressed views of similar aspects of NOS in the VNOS-C (refer to Section 7.5 for more details).

This was not necessarily the case in scientific contexts, as results indicated that some participants' expressed views of aspects of NOS in these contexts were not aligned with their expressed views of similar aspects of NOS in the VNOS-C (refer to Section 7.6 for more details). Possible explanations for these findings may relate to the presence of multiple epistemologies.

Previous research has indicated that participants possess both general epistemologies of knowledge, and specific scientific epistemologies. Bell and Lederman (2003) examined university professors' and research scientists' views of NOS, and their decision-making on a selection of socioscientific issues, and stated that the decisions made by participants in their study may have reflected their general epistemologies of knowledge, rather than their specific scientific epistemologies. Following Schommer and Walker (1995), they proposed that:

> …when responding to the science-specific items of the VNOS, which required metacognition about the construction of scientific knowledge, participants' absolute views of science were evident. But when responding to the issues of the DMQ (Decision making questionnaire) which had strong social components, the participants found themselves on more familiar ground and were able to apply their general epistemologies of knowledge. (Bell & Lederman, 2003, p. 367)

Findings from this study lend support for this proposition. Tom and Sarah possessed relatively stronger background scientific knowledge compared with Rachel, Monica and David. Tom and Sarah appeared to draw on their specific science epistemological knowledge when responding to the superconductors survey situated in a scientific context, but were able to apply their general epistemologies of knowledge when responding to course components situated in socioscientific contexts (e.g., global warming task). Conversely, Rachel, Monica and David, who possessed relatively weaker background scientific knowledge, and did not appear to draw on specific science epistemologies. These participants were able to apply their general epistemologies of knowledge across scientific and socioscientific contexts, providing an explanation for the alignment of their expressed views of NOS over all of the assessments.

These findings are consistent with those of Leach et al. (2000) who proposed that participants can draw on multiple forms of epistemological reasoning in differing contexts. They state that different contexts place different demands on participants, and the application of particular forms of epistemological reasoning may be more or less appropriate depending on the context under investigation. For example, when participants are designing experiments, they may focus primarily on data collection techniques and procedures, thus drawing on data focused epistemological views (refer to Section 5.9.1.3 for an explanation of data focused, model focused and relativist focused epistemological views). Conversely, during data analysis, they may focus primarily on theoretical issues, consequently drawing on model focused or relativist focused epistemological views. The application of appropriate epistemological reasoning during relevant stages of scientific investigation is stressed in these situations.

It is important to note that participants may not be conscious of the epistemological reasoning they are utilising during different stages of scientific investigation. In this study, the prominence of data focused epistemological views expressed by Tom, Sarah, and David, in response to questions regarding data analysis and interpretation during the superconductors survey, reflect an inappropriate application of epistemological reasoning in this context.

8.2.1.2 Difficulties in engaging in argumentation in scientific contexts

Another finding from this study indicated that participants engaged in the argumentative nature of the global warming task, but did not engage in argumentation during the laboratory project; suggesting that engagement in argumentation in scientific contexts is more difficult than engagement in argumentation in socioscientific contexts. Osborne et al. (2004a) support this proposition, and state that argumentation in scientific contexts requires the application of relevant scientific knowledge to enable participants to support and justify their arguments. In this study, participants were not provided with specific scientific information to aid their participation in argumentation in the laboratory project. Participants were required to access information about different chemicals, and their lack of background chemical science knowledge may have inhibited their ability to select appropriate chemicals to test.

On the other hand, argumentation in socioscientific contexts does not place the same conceptual demands on participants, as they can utilise and apply informal knowledge gained through previous life experiences to support and justify their arguments. In addition, socioscientific contexts often utilise topics that are personally interesting and contemporary, providing participants with added incentive and motivation to engage in argumentation in these contexts. Zeidler, Sadler, Callahan, Burek, and Applebaum (2007) posit that when these topics are coupled with classroom debates and discussion, participants are able to challenge their pre-existing beliefs about a topic. These factors may have contributed to participants' ease of engagement in argumentation in socioscientific contexts in this study.

An apparent disadvantage of argumentation in socioscientific contexts is that participants may only draw upon their own life experiences to support their claims, and dismiss relevant scientific evidence when engaged in these contexts. Thus, it is important to emphasise the role of scientific evidence in socioscientific contexts, in addition to a consideration of informal knowledge, and moral and ethical values. In this study, participants were provided with scientific evidence to aid in supporting and justifying their positions during the global warming task. Other findings in this study indicated that the mode of argumentation influenced participants' engagement in the various course components. These findings will be considered in the following section.

8.2.2 Mode of argumentation

Two modes of argumentation, oral and written, were utilised in this study to provide contexts for participants to engage in argumentation. This section will examine the implications of engaging in oral and written argumentation, as findings from this study indicated that engaging in oral argumentation during the argumentation scenarios presented challenges for some of the participants (refer to Section 7.4.2.2 for more details).

Two of the participants (Rachel and Sarah) expressed that they had not enjoyed engaging in oral argumentation during the course. They expressed a lack of confidence in their scientific knowledge[2] compared to other members of the class. These findings suggest that a perceived lack of scientific content knowledge may hinder participants' engagement in argumentation tasks. Kuhn (1993) supports this view stating that engaging in argumentation in scientific contexts may be difficult for participants, as their perceived lack of science content knowledge may limit their engagement in the science topic under investigation. She suggests that engaging in socioscientific argumentation may place less demands on participants as they may feel more confident in their perceived knowledge about the topic. In this study, Rachel and Sarah expressed that they did not enjoy engaging in oral argumentation, regardless of whether the argumentation was situated in scientific or socioscientific contexts.

Another possible explanation for this dissatisfaction in engaging in argumentation has been suggested by Clark and Sampson (2006), who state that some participants may feel marginalised during oral argumentation, due to the dominance of other participants during argumentative activities. In this study, Tom and David were observed to be active participants during oral argumentation, who both expressed that they enjoyed 'winning arguments'. These participants dominated oral argumentation discourse during the argumentation scenarios. Jimenez-Alexiandre, Eirexas, and Agraso (2006) highlight the limitations of focusing on 'winning arguments' stating that rational, sound argumentation may be compromised by adopting this position. Other findings from Jimenez-Aleixandre et al.'s (2006) study indicated that the arguments participants supported in group, oral situations were not always aligned with the

[2] This was an interesting finding as Sarah possessed a relatively high level of background scientific knowledge compared to other class members, but perceived this knowledge to be less developed than other class members' scientific knowledge.

arguments they supported in their individual, written reports. She suggested that due to the different nature of oral and written argumentation, it is important to ensure participants are exposed to both modes of argumentation, to enable a richer assessment of their argumentation to be obtained.

An additional finding reported in this study found that Rachel expressed that she did not feel she possessed sufficient skills of argumentation to participate in oral argumentation, but did feel confident to engage in written argumentation. Written argumentation has the added advantage of providing a context for reflection about NOS ideas. Narayan (2006, p. 33) has highlighted the advantages of utilising written argumentation stating:

> Writing provides the process needed to relate new knowledge to prior experience (synthesis). …The written material, the product of this process, is concrete and visible and permits review, manipulation and modification of knowledge as it is 'learned' and put into a framework.

An analysis of participants' written arguments provided in the global warming essays revealed numerous explicit references to NOS aspects examined in the study. Aspects of NOS reflected in the global warming essays were also the aspects of NOS cited by participants when they were asked to define NOS during the final interview, and were also the most developed aspects of NOS assessed by the VNOS-C over the duration of the study. These findings indicate that the global warming essay may have provided a context for reflection about NOS ideas. Conversely, there were very few explicit references to NOS aspects in the oral argumentation scenarios[3], lending support for the importance of including written argumentation tasks in this study.

8.3 Task-specific factors

A consideration of the results obtained from an analysis of the six course components implemented during the study (refer to Chapter 7 for more details), facilitated the identification of three task-specific factors that mediated the development of participants' views of the examined NOS aspects: (a) argumentation scaffolds, (b) epistemological probes, and (c) consideration of alternative data and explanations. These factors will be considered in the following sub-sections.

8.3.1 Argumentation scaffolds

Findings from this study highlight the importance of providing argumentation scaffolds to facilitate engagement in argumentation contexts. An argumentation scaffold is a written or verbal prompt that encourages participants to engage in argumentation. Argumentation scaffolds should be used in conjunction with explicit argumentation instruction to ensure participants are familiar with the various definitions and meanings of argumentation components, such as data, claims, warrants, backings, rebuttals, qualifiers, etc.

Participants were provided with argumentation scaffolds during the argumentation scenarios (refer to Section 7.4 for more details). Participants engaged in the argumentation scenarios after sessions of explicit argumentation

[3] It is important to note that no explicit references to NOS aspects were evident in participants' written laboratory projects, but as results indicated that participants did not engage in the argumentative nature of this task, this was not an unexpected finding.

instruction, in which relevant aspects of argumentation were highlighted. They were encouraged to utilise this information during the scenarios, and were verbally prompted by the researcher to consider relevant argumentation aspects (such as claims, data, warrants, qualifiers, etc.) during the scenarios. Argumentation scaffolds were also provided in the global warming task (refer to Section 7.5 for more details), via written assessment criteria that explicitly asked participants to develop an argument and counterargument to support and justify their position on the issue. These argumentation scaffolds were successful in enabling participants to engage in argumentation in both of these tasks.

No argumentation scaffolds were utilised in the laboratory project (refer to Section 7.7. for more details). Written assessment criteria did not explicitly ask participants to develop an argument and counterargument to support and justify their position. It was assumed that participants would select, compare, and test a number of chemicals; develop a scientific argument to justify their selection of the most effective chemical; and also provide counterarguments to support their choice of one particular chemical over other chemicals. Results indicated that participants did not engage in argumentation in this task, and many of the participants simply presented empirical data with minimal scientific interpretation. There was little attempt to convince the reader of why one chemical was more effective than another chemical.

Similar findings were reported by Kuhn and Reiser (2006) who provide an example of a classroom task where students were required to conduct research on different atoms, and design an oral presentation to convince fellow students to ‘buy’ their atom. The task had been designed with the aim of engaging students in scientific argumentation, but results indicated that this goal was not achieved. Student presentations tended to focus on scientific content knowledge about atoms, with only a few of the student presentations addressing the task goal of attempting to ‘sell’ their atom.

The lack of emphasis on scientific argumentation is mirrored in this study, whereby participants generally presented written laboratory reports focused on reporting data, with arguments supporting the most ‘effective’ chemical notably absent. Participants may have believed that the data were self-evident, and did not require interpretation, or justification; or alternatively they may have believed the researcher already knew why the data were important, and therefore it only mattered to include the data. These possibilities have been discussed in previous studies (Sandoval & Millwood, 2005; Kuhn & Reiser, 2006). Thus, engagement in argumentation in this task may have been influenced by whether participants perceived a need to explain their data.

In addition, participants were required to present the findings of their laboratory projects in a seminar format at the end of the main intervention phase of the study. During these presentations, the researcher did not verbally prompt participants to challenge each other’s explanations and conclusions. Kuhn and Reiser (2006) have proposed that teachers must ‘create a need’ for students to engage in argumentation, and have suggested that activities such as argument jigsaws (whereby pairs of students compare and justify ideas, and reach a group consensus), which force participants to consider each other’s ideas; and whole class debates, can be incorporated to achieve this goal. Thus, the lack of provision of argumentation scaffolds in the laboratory project may have compromised participants' engagement in argumentation in this task.

8.3.2 Epistemological probes

An analysis of the findings of this study indicate that the inclusion of epistemological probes was influential to the development of participants' views of some aspects of NOS. An epistemological probe is a written or verbal prompt that orients the participants' attention to relevant NOS aspects highlighted in a task, or focuses the participants' attention on a question designed to draw on their epistemological knowledge or reasoning. Epistemological probes should be used in conjunction with explicit NOS instruction to ensure participants are familiar with the definitions and meanings of various aspects of NOS, such as the creative and imaginative NOS, the social and cultural NOS, the methods of science, etc.

Epistemological probes were included in the global warming survey and superconductors survey[4]. The global warming survey (refer to Section 7.5.1 for more details) utilised a set of guiding questions that explicitly drew participants' attention to two aspects of NOS examined in this study, the subjective and theory-laden NOS, and the social and cultural NOS. An analysis of the results from the global warming survey indicated that the survey was effective in providing opportunities for participants to apply their understandings of these specific aspects of NOS to their reasoning in a socioscientific context. The same specific NOS aspects (amongst others) were explicitly referred to in participants'

[4] The superconductors survey contained epistemological probes, but as this task was also utilised to assess participants' views of some aspects of NOS, this was not unexpected.

written global warming essays, providing evidence of the effectiveness of these epistemological probes in orienting participants' attention to relevant NOS aspects highlighted in a task.

Epistemological probes were not utilised in the laboratory project[5] or the argumentation scenarios. Results indicated that some of the participants explicitly cited the argumentation scenarios as a context for learning about NOS, but very few explicit references to NOS aspects were reflected in their argumentative discourse as they engaged in the argumentation scenarios (refer to Section 7.4.1 for more details). Although the researcher in this study provided explicit NOS instruction throughout the course, and conducted class discussions at the end of each argumentation scenario, she did not explicitly draw participants' attention to relevant aspects of NOS during the scenarios. Thus, participants were not given direct guidance in applying specific views of NOS to their reasoning in the argumentation scenarios. These findings suggest that the lack of utilisation of epistemological probes in this task hindered participants' abilities to apply their views of NOS to their reasoning in the argumentation scenarios.

8.3.3 Consideration of alternative data and explanations

The consideration of alternative data and explanations is an important factor influencing participants' engagement in argumentation. As discussed previously, possible explanations for participants' lack of engagement in the argumentative nature of the laboratory project include a lack of relevant scientific content knowledge (refer to Section 8.2.1.2 for more details), and the non-inclusion of

[5] As participants did not engage in argumentation in this task, it is irrelevant to discuss the possible application of their views of NOS to their reasoning in this task.

argumentation scaffolds in the task (refer to Section 8.3.1 for more details). A third factor identified that may have facilitated participants' engagement in argumentation, was the inclusion of alternative data and explanations.

A closer analysis of participants' written laboratory reports indicated that many of the participants only choose to test a couple of chemicals, with Sarah's group only testing one chemical. These findings suggest that unless participants are explicitly instructed to research and test a range of chemicals, or a particular quantity of chemicals, they may make a decision about the most effective chemical without considering suitable alternatives. This failure to consider, test and evaluate possible alternatives, limits participants' abilities to engage in the argumentative nature of the task. The failure to consider the possibility of alternative explanations has been reported in previous studies (e.g., Bell & Linn, 2000; Kuhn, 1991, 1993). Conversely, in the global warming task, participants were presented with two opposing views of the phenomenon. These opposing views were clearly described, comprehensive in detail, and both views contained similar amounts of scientific evidence and persuasive text. The provision of alternative explanations forced participants to evaluate multiple perspectives on the issue.

These findings suggest that participants may have engaged in the argumentative nature of the laboratory project if it had been designed to allow competing ideas to be tested. For example, the researcher could have provided a list of alternatives (chemicals) and asked the participants to research and test the chemicals, and then to provide an argument as to why chemical A, was more effective than chemical

B, or chemical C, etc. This consideration of alternatives would have forced participants to consider and evaluate other sources of evidence, and then justify their decisions after considering the alternatives presented. Thus, a lack of provision of alternative data and explanations may hinder participants' engagement in argumentation.

8.4 Personal factors

A consideration of the results of the study that were analysed and presented in Chapter 6, facilitated the identification of three personal factors that mediated the development of participants' views of the examined NOS aspects: (a) perceived previous knowledge about NOS, (b) appreciation of the importance and utility value of NOS, and (c) durability and persistence of pre-existing beliefs. These factors will be considered in the following sub-sections.

8.4.1 Perceived previous knowledge about NOS

Findings from this study suggest that perceived previous knowledge about NOS hindered the development of participants' NOS views. Although all of the participants expressed similar views of NOS at the commencement of the study, there were differential gains noted in the development of individual participants' views of the examined NOS aspects. Rachel and Monica did not show confidence in their pre-existing views of NOS, and exhibited the most substantial development in their views of the examined NOS aspects. Tom and Sarah expressed that they already knew about NOS at the commencement of the study, although at the end of the study they did express that they had learned some new ideas. These participants exhibited development in their views of many of the examined NOS aspects, but this development was less pronounced than the development exhibited by Rachel and Monica. David also expressed that he already knew about NOS at the commencement of the study, but stated that he had not learnt any new ideas about NOS in the course, and subsequently did not exhibit any substantial development in his views.

These findings indicate that there was not as much incentive for David, and to a lesser extent, Tom and Sarah, to be receptive to learning more about NOS, as they did not initially recognise a need to change their pre-existing views. Conversely, Rachel and Monica recognised that they did not know a lot about NOS at the beginning of the study, and were more receptive to learning new ideas to clarify and develop their views. Similar findings have been reported by Schwartz et al. (2004). Why did Tom and Sarah end up changing their views of NOS, and recognise that they did learn something in the course? Why did David feel that he hadn't learnt anything new? A possible explanation for these findings relates to the generation of cognitive dissonance (Novak, 1977).

Findings from this study suggest that cognitive dissonance was generated for all of the participants, except David, during the course. Schwartz and Lederman (2002) suggest that the generation of cognitive dissonance is a vital first step in enabling the development of NOS views, regardless of the confidence in pre-existing views of NOS expressed by the participant. This dissonance between participants' less desirable views of NOS expressed at the commencement of the study, and the more desirable views of NOS explicitly introduced during the study, was recognised early in the study by Rachel and Monica. Tom and Sarah's perceived previous knowledge about NOS impeded the generation of cognitive dissonance early in the course, but as they engaged in the various course components and began to recognise the deficiencies in many of their NOS views, they were able to accommodate new understandings of NOS that were generally aligned with NOS understandings introduced during the course. Similar findings were reported by Schwartz and Lederman (2002).

Conversely, the generation of cognitive dissonance did not occur for David until the end of the final interview, conducted during the post-intervention phase of the study. David’s pre-existing views of NOS were deeply in-grained, and very resistant to shifting. Even when he was presented with evidence that invalidated his views, he was not prepared to change his views. It was not until the very end of the final interview, during a follow-up discussion of the VNOS-C, where evidence was furnished that David had finally recognised dissonance between his pre-existing views of NOS, and the views of NOS presented in the course:

> …maybe these two interviews and everything we did in the subject is now starting to make me think that up till now I’ve just been agreeing with science blindly. (David, VNOS-Post, Q3)

This generation of cognitive dissonance at the end of study occurred after the administration of the post-intervention VNOS-C, and highlights the importance of providing contexts for reflection about NOS views. The administration of the VNOS-C and follow-up interviews provided a context for engaging in reflection about NOS ideas, by forcing participants to explore and clarify their views of NOS. These findings are consistent with those reported by Abd-El-Khalick and Akerson (2004), and Schwartz and Lederman (2006).

8.4.2 Appreciation of the importance and utility value of NOS

Other findings from this study suggest that a lack of appreciation of the importance and utility value of learning about NOS, may hinder the development of participants' NOS views. Rachel, Monica, Tom, and to a lesser degree, Sarah, all recognised the importance and usefulness of learning about NOS in the course. These participants expressed that learning about NOS enhanced their learning of the other course content. Conversely, although David stated that he had enjoyed learning about NOS in the course, he did not appreciate the importance or utility value of learning about NOS, and viewed the inclusion of NOS simply as a novel teaching approach, designed to make learning science more interesting. Thus, he was not motivated to change his pre-existing views, as he failed to recognise the importance of internalising more desirable understandings of NOS to facilitate effective learning or teaching of science. Abd-El-Khalick and Akerson (2004) refer to the internalisation of the importance and utility value of NOS as a motivational factor, and the findings of their study suggest that participants who developed more desirable views of NOS internalised the importance of teaching and learning about NOS. This study lends support for this assertion. Implications of these findings suggest that an explicit rationale for learning about NOS should be provided at the beginning of studies that aim to develop participants' views of NOS.

8.4.3 Durability and persistence of pre-existing beliefs

As discussed in the Section 8.4.1, participants' perceived previous knowledge about NOS hindered the development of participants' NOS views. This section will discuss the impact of background life experience on participants' views of NOS. The durability and persistence of pre-existing beliefs that stem from participants' life experiences are highlighted whilst examining the case of David.

David was the oldest participant in the study. At 46 years of age he had a considerable number of years of life experience behind him. Rachel, Monica and Sarah were all aged between 19-21 years, and Tom was 30 years old. Previous research has highlighted the durability of participants' views and beliefs, and the difficulties experienced in attempting to change pre-existing views (Akerson et al., 2000; Kuhn, 1991). David's views of NOS had developed over the course of his school education, and also over nearly 30 years of post-school experiences. As such, it may be unrealistic to expect him to substantially change his views of the examined aspects of NOS over the relatively short time frame of a single university semester, compared to the relatively long period of time he has held the same views of NOS, many of which have probably never been challenged. Thus, the reality of David discarding his pre-existing NOS views for a new set of NOS views is somewhat naïve.

The tenacity with which participants' hold on to their pre-existing views of NOS has been documented by Akerson et al. (2000). They recommend that participants are made explicitly aware of the inadequacies of their views of NOS at the beginning of the course, to ensure that they experience cognitive dissonance regarding their views of NOS. As stated earlier, David did not experience any cognitive dissonance until the end of the study, although it should be noted that he was not made explicitly aware of the inadequacies of his views by the researcher during the study (nor were the other participants). Unlike the other four participants who did become aware of some of the inadequacies of their views of NOS throughout the study whilst taking part in the various course components, David did not become aware of the inadequacies of his NOS views.

David's lack of development in NOS views can also be explained by examining the phenomenon of 'belief persistence' (Kuhn, 1991). Belief persistence recognises that participant's beliefs persist for an extended time after evidence has been furnished that discredits the original belief. Examples of belief persistence were evident in David's VNOS-C responses, and during the various course components. A notable example was expressed during the pre-intervention VNOS-C, in response to a question about atomic structure:

> I have put my faith in the honesty of the scientists. This observation is the only one I am aware of and no-one has ever disputed it to my knowledge, so it must be true. …I'd put my faith in the fact that we've been taught that ever since I was a boy or since high school anyway that that's what made up an atom, I put my faith in the honesty of the scientists… (David, VNOS-Pre, Q6)

Little change was noted in David's response to the same question during the post-intervention VNOS-C:

> Well, that's one of those silly things that I can't explain… Right now I've never seen one, I put my faith in science… I suppose it's part of my personality, my psyche, I'm just scientifically inclined. And I blindly believe the scientists. (David, VNOS-Post, Q1)

Thus, the persistence of David's pre-existing beliefs influenced his ability to disavow himself of his pre-existing position, and subsequently accommodate a new perspective. As noted in Section 8.4.1, David did experience cognitive dissonance at the end of the study, but implications drawn from the above discussion highlight the importance of making participants explicitly aware of the inadequacies of their pre-existing views of NOS at the commencement of the study. It cannot be assumed that participants will recognise these inadequacies on their own, particularly if their views of NOS have been developed and reinforced over an extended period of time. The following section will provide a summary of the chapter.

8.5 Summary

The purpose of this chapter was to identify and critically examine the various contextual, task-specific, and personal factors that mediated the development of participants' views of the examined NOS aspects. These identified factors included factors that directly mediated participants' views of NOS, and also factors that indirectly mediated participants' views of NOS by influencing their engagement in argumentation. Two contextual factors were found to mediate the development of participants' views of the examined NOS aspects in this study: (a) context of argumentation (scientific and socioscientific), and (b) mode of argumentation (oral and written).

An analysis of the context of argumentation in this study identified the influence of multiple epistemologies on participants' reasoning in scientific and socioscientific contexts, and highlighted some of the difficulties of engaging in argumentation in scientific contexts. Participants may draw on multiple forms of epistemological reasoning in differing contexts, and may not be conscious of the epistemological reasoning they are utilising in these contexts. Participants with relatively stronger background scientific knowledge in this study drew on specific science epistemological knowledge in scientific contexts, but applied their general epistemologies of knowledge in socioscientific contexts. A consideration of these factors highlights the importance of applying appropriate epistemological reasoning during argumentation activities.

Engaging in argumentation in scientific contexts was more difficult than engaging in argumentation in socioscientific contexts for participants in this study. A lack of provision of specific scientific content knowledge was one identified factor that hindered participants' engagement in argumentation in some scientific contexts in this study. Argumentation in socioscientific contexts may not have placed the same conceptual demands on participants in this study, enabling them to utilise and apply informal knowledge gained through previous life experiences to support and justify their arguments, in addition to applying relevant scientific evidence in these contexts.

Two modes of argumentation, oral and written, were utilised in this study to provide contexts for participants to engage in argumentation. Engaging in oral argumentation presented challenges for some participants in this study due to a perceived lack of scientific content knowledge, insufficient skills of oral argumentation, and the group dynamics present in the classroom. Written argumentation did not present these same challenges, and had the added advantage of providing a context for reflection about NOS ideas, that enabled participants to apply and develop their views of NOS more effectively than in oral contexts.

Three task-specific factors were found to mediate the development of participants' views of the examined NOS aspects in this study: (a) argumentation scaffolds, (b) epistemological probes, and (c) consideration of alternative data and explanations. The inclusion of argumentation scaffolds facilitated participants' engagement in argumentation in this study. Used in conjunction with explicit argumentation instruction, these written or verbal prompts were effective in encouraging participants to engage in argumentation. The lack of engagement in argumentation in scientific contexts in this study may have been influenced by whether participants perceived a need to explain their data, thus stressing the importance of creating a need for participants to engage in argumentation.

The inclusion of epistemological probes was influential to the development of participants' views of NOS in this study. Used in conjunction with explicit NOS instruction, these written or verbal prompts were successful in orienting participants' attention to relevant NOS aspects highlighted in a task, and/or focusing participants' attention on a question designed to draw on their epistemological knowledge or reasoning. The lack of epistemological probes in some tasks in this study hindered participants' abilities to apply their views of NOS to their reasoning during argumentation.

Considering alternative data and explanations influenced participants' engagement in argumentation in this study. The provision of alternative data and explanations forces participants to consider and evaluate multiple sources of data and explanations. Findings from this study support the assertion that without the provision of alternative data, participants may simply select and evaluate one possible alternative, thus limiting their engagement in argumentation.

Three personal factors were found to mediate the development of participants' views of the examined NOS aspects in this study: (a) perceived previous knowledge about NOS, (b) appreciation of the importance and utility value of NOS, and (c) durability and persistence of pre-existing beliefs. Perceived previous knowledge about NOS hindered the development of participants' NOS views in this study. Participants who expressed that they already knew about NOS did not have as much incentive to be receptive to learning more about NOS, as they did not initially recognise a need to change their pre-existing views. Conversely, participants who recognised that they did not know a lot about NOS, were more receptive to learning new ideas to clarify and develop their views of NOS, and the development of these participants' views of NOS was relatively more substantial than those participants who held more confidence in their pre-existing views.

Cognitive dissonance was generated for all of the participants at various stages throughout the study as they recognised the deficiencies in many of their NOS views, and sought to find alternative views of NOS congruent with NOS understandings introduced during the course. The administration of the VNOS-C and follow-up interviews in this study provided a context for engaging in reflection about NOS ideas, by forcing participants to explore and clarify their views of NOS.

A lack of appreciation of the importance and utility value of learning about NOS hindered the development of participants' NOS views in this study. The participant who failed to recognise the importance of developing informed understandings of NOS to the learning and teaching of science was not motivated to change his pre-existing views of NOS in this study. A consideration of these factors suggests that an explicit rationale for learning about NOS should be provided at the beginning of studies that seek to improve participants' views of NOS.

The durability and persistence of participants' pre-existing beliefs was identified as a third personal factor mediating the development of participants' NOS views in this study. The influence of considerable background life experience for one of the participants in this study limited his ability to discard his previously unchallenged, and largely naïve views of NOS, to accommodate new understandings. The durability of pre-existing views of NOS is highlighted in this instance, and relates to the phenomenon of belief persistence which recognises that participants' beliefs persist for an extended time after evidence has been furnished that discredits the original belief (Kuhn, 1991). A consideration of these factors highlights the importance of making participants explicitly aware of the inadequacies of their pre-existing views of NOS at the commencement of a study, as it cannot be assumed that participants will realise these inadequacies on their own, particularly if their views of NOS have been developed and reinforced over an extended period of time.

In conclusion, findings from this chapter provided evidence to address the third research question:

> *What factors mediated the development of preservice primary teachers' views of the examined aspects of NOS?*

Three sets of factors were found to mediate the development of participants' views of the examined aspects of NOS in this study - contextual, task-specific, and personal. Two contextual factors were identified: (a) context of argumentation (scientific and socioscientific), including a consideration of multiple epistemologies, and the difficulties in engaging in argumentation in scientific contexts; and (b) mode of argumentation (oral and written). Three task-specific factors were identified: (a) argumentation scaffolds, (b) epistemological probes, and (c) consideration of alternative data and explanations; and three personal factors were identified: (a) perceived previous knowledge about NOS, (b) appreciation of the importance and utility value of NOS, and (c) durability and persistence of pre-existing beliefs.

The following chapter will provide a summary of the study, followed by a discussion of the limitations of the study. Major conclusions emanating from the study will then be outlined, followed by a discussion of implications and recommendations for future studies.

CHAPTER 9 – CONCLUSION

9.1 Introduction

The aim of this study was to explore the influence of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS. This chapter will provide a summary of the study, followed by a discussion of the limitations of the study. Major conclusions emanating from the study will then be outlined, followed by a discussion of implications and recommendations for future studies.

9.2 Summary of the study

Chapter 1 provided a rationale for exploring NOS and argumentation in this study. The aim of the study was outlined in this chapter, in addition to the three research questions guiding this study. Chapter 2 provided a comprehensive overview of research conducted in the field of NOS. The purpose of this review was to situate the study within the broader context of NOS research, and to critically analyse recent NOS teaching approaches designed to develop or improve students' and teachers' views of NOS. The review provided evidence to support the adoption of an explicit, contextualised approach to NOS instruction to aid in developing preservice primary teachers' views of NOS. Implementing this instruction within a science content course was proposed, to provide an optimal environment for allowing teachers to develop the necessary skills and instructional strategies needed to both develop informed views of NOS, and successfully apply these views of NOS in their classroom practice.

An overview of research in the field of argumentation, with a specific focus on studies conducted in science education, was provided in Chapter 3. The purpose of the review was to situate the study within the broader context of argumentation research, and to critically analyse the various modes and contexts of argumentation instruction. Implications drawn from the review suggest that students and teachers need to be explicitly guided in developing and applying skills of argumentation in both scientific and socioscientific contexts, and that the application of relevant conceptual knowledge may be needed (particularly in scientific contexts), to ensure students and teachers are able to engage in argumentation effectively. Thus, the review identified explicit argumentation instruction, context of argumentation, and conceptual knowledge as influential factors affecting individuals' skills and/or quality of argumentation.

Chapter 4 provided a detailed overview of an emerging area of research exploring NOS and argumentation. A rationale was outlined for investigating possible links between NOS and argumentation. The purpose of the review was to identify trends in the current research base, and an analysis of the nine empirical studies conducted in this area highlighted the importance of incorporating both explicit argumentation instruction, and explicit NOS instruction in studies that aim to develop students' and teachers' views of NOS. Implications drawn from the review suggest that learners need to recognise the relevance of applying their understandings of NOS to their arguments to ensure that the arguments they develop are informed by epistemological considerations, and not narrowly focused on personal factors or pre-existing views. On the basis of these findings, the tentative claim was forwarded that integrating explicit NOS and argumentation instruction in the science classroom, and allowing learners to apply their views of NOS to their reasoning and arguments in scientific and/or socioscientific contexts, may lead to developments in their views of NOS. The present study was designed to examine this claim.

A consideration of the broad literature base examined in Chapters 2-4 informed the aims and design of this study. The aim of the study was to explore the influence of a science content course incorporating explicit NOS and argumentation instruction on preservice primary teachers' views of NOS. The study incorporated a classroom intervention designed to include explicit, contextualised NOS instruction within a science content course. The course utilised scientific and socioscientific contexts for argumentation, and provided opportunities for preservice primary teachers to apply their NOS understandings to their arguments. Explicit argumentation instruction was also implemented throughout the classroom intervention.

A comprehensive overview of the research design, developed to address the aim of the study, was provided in Chapter 5. The purpose of the chapter was to provide a justification for the research design employed in the study. A constructivist research perspective guided the study, and the research strategy employed was case study research. The study applied trustworthiness criteria (Guba & Lincoln, 1989), and methodological triangulation protocols (Denzin, 1984); and also considered the perspective and role of the researcher, to ensure the studies' findings and interpretations were valid.

This study was conducted with preservice primary teachers enrolled in a single-semester science content course. Five preservice primary teachers were selected for intensive investigation, and became case study participants in the study. Six course components were designed and implemented in the study to aid in the development of participants' views of NOS. These course components were (a) explicit NOS instruction, (b) explicit argumentation instruction, (c) argumentation scenarios, (d) global warming task, (e) superconductors survey, and (f) laboratory project.

Four primary sources of data were used to provide evidence for the interpretations, recommendations and implications that emerged during the course of the study. The data sources included questionnaires and surveys, interviews, audio- and video-taped class sessions, and written artefacts. Data analysis was conducted at the conclusion of the study and involved the formation of various assertions that informed the major findings of the study. A variety of validity and ethical protocols were considered during the analysis to ensure the findings and interpretations emerging from the data were valid.

The purpose of the Chapter 6 was to explore the change (or lack thereof) in participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. The chapter provided a comprehensive assessment of participants' pre- and post-intervention views of the examined aspects of NOS. Findings from this assessment provided evidence to address the first research question:

a. *What are preservice primary teachers' initial views of the examined aspects of NOS?*
b. *Do their views of these aspects of NOS change over the course of the intervention?*

All of the participants expressed naïve and/or limited views of six or more of the eight examined NOS aspects at the commencement of the study. Many positive changes were evident at the end of the intervention with four of the five participants (Rachel, Monica, Tom and Sarah) expressing partially informed and/or informed views of five or more of the eight examined NOS aspects. These four participants experienced development in at least five of the eight examined aspects. David's largely naïve and/or limited views of the examined NOS aspects remained relatively unchanged at the conclusion of the intervention. Participants' views of the subjective and theory-laden NOS, the social and cultural NOS, and the creative and imaginative NOS, were the most developed aspects of NOS assessed in this study. Conversely, participants' views of theories and laws were the least developed aspect of NOS assessed in this study.

Three important trends in the data pertaining to the development of participants' NOS views in this study were identified. First, an examination of participants' definitions of NOS expressed in the final interview corresponded positively to the aspects of NOS that developed most substantially in the VNOS-C. Second, participants' perceived previous knowledge about NOS appeared to influence the development of their NOS views; and third, a lack of appreciation of the importance and utility value of learning about NOS appeared to influence the development of participants' views of NOS.

The purpose of Chapter 7 was to evaluate the influence of the course components on participants' views of the examined NOS aspects, and to identify trends in the data pertaining to the development of participants' NOS views. Findings from this analysis provided evidence to address the second research question:

> *What is the influence of the various course components implemented during the study, on preservice primary teachers' views of the examined aspects of NOS?*

The inclusion of explicit NOS instruction aided some of the participants' understandings of a couple of the examined NOS aspects, although references to specific explicit NOS instructional activities in participants' final interview responses were infrequently cited. Importantly, the inclusion of explicit NOS instruction is considered to be a necessary pre-requisite for developing informed understandings of NOS, to enable participants to familiarise themselves with descriptions of the various aspects of NOS, and to enable them to compare these descriptions with their pre-existing views of NOS.

The infrequent citing of explicit argumentation instruction by participants was not unexpected as this course component was primarily designed and implemented in the study with the aim of familiarising participants with descriptions of the various components of an argument, and to facilitate participants' engagement in the argumentative aspects of the other course components (e.g., argumentation scenarios, global warming task, superconductors survey, and laboratory project).

Although some of the participants explicitly cited the argumentation scenarios as a context for learning about NOS, very few explicit references to NOS aspects were reflected in their argumentative discourse whilst engaged in the scenarios. Factors such as perceived science content knowledge, skills of argumentation, and group dynamics influenced some participants' engagement in oral argumentation, therefore impacting on their participation in the argumentation scenarios. In addition a lack of appreciation of the importance and usefulness of argumentation hindered some participants' engagement in the argumentation scenarios.

The global warming task enabled participants to apply their understandings of aspects of NOS to their reasoning in a socioscientific context. Participants' views of some aspects of NOS expressed in the global warming survey aligned with their expressed views of these aspects in the VNOS-C, providing evidence to suggest that views of NOS expressed in the VNOS-C are similar to those expressed in a socioscientific context (global warming task). Participants engaged in argumentation in their global warming essays. Numerous references to many of the examined aspects of NOS were evident throughout participants' global warming essays, suggesting that the global warming task highlighted the application of specific NOS aspects, and provided an effective context to enable participants to apply their views and understandings of many aspects of NOS to their reasoning in the task.

Although the superconductors survey provided an effective context for participants to express and apply their understandings of aspects of NOS to their reasoning in a scientific context, only one participant cited the survey as an example of a NOS learning context in the study. All of the participants exhibited broadly data focused views of the three parts of the superconductors survey at the commencement of the study. Two participants experienced a change in overall view from a broadly data focused view to a broadly relativist focused view at the end of the study, with the three remaining participants expressing little change in their pre- and post-intervention views. A comparison of participants' views of similar aspects of NOS across the superconductors survey and VNOS-C, indicated that factors such as previous scientific knowledge influenced participants' expressed views of NOS in scientific contexts.

There were no explicit references to aspects of NOS in any of the participants' written laboratory reports. None of the participants referred to the laboratory project as influencing their views of NOS, and no references to this course component were evident in any of the participants' responses during the final interview.

The purpose of Chapter 8 was to identify and critically examine the various contextual, task-specific, and personal factors that mediated the development of participants' views of the examined NOS aspects in this study. The identified factors discussed in the chapter included factors that directly mediated participants' views of NOS, and also factors that indirectly mediated participants' views of NOS by influencing their engagement in argumentation. Findings from this analysis provided evidence to address the third research question:

> *What factors mediated the development of preservice primary teachers' views of the examined aspects of NOS?*

Two contextual factors were found to mediate the development of participants' views of the examined NOS aspects in the study: (a) context of argumentation (scientific and socioscientific), and (b) mode of argumentation (oral and written).

An analysis of the context of argumentation in the study identified the influence of multiple epistemologies on participants' reasoning in scientific and socioscientific contexts, and highlighted some of the difficulties of engaging in argumentation in scientific contexts. Implications drawn from the analysis indicated that participants may draw on multiple forms of epistemological reasoning in differing contexts, and may not be conscious of the epistemological reasoning they are utilising in these contexts. Participants with relatively stronger background scientific knowledge in the study drew on specific science epistemological knowledge in scientific contexts, but applied their general epistemologies of knowledge in socioscientific contexts. A consideration of these factors highlighted the importance of applying appropriate epistemological reasoning during argumentation activities.

Engaging in argumentation in scientific contexts was found to be more difficult than engaging in argumentation in socioscientific contexts for participants in the study. A lack of provision of specific scientific content knowledge was one identified factor that hindered participants' engagement in argumentation in some scientific contexts in the study. Implications drawn from the chapter suggest that argumentation in socioscientific contexts does not place the same conceptual demands on participants, as they can utilise and apply informal knowledge gained through previous life experiences to support and justify their arguments, although it is also important to emphasise the role of scientific evidence in these contexts.

Two modes of argumentation, oral and written, were utilised in the study to provide contexts for participants to engage in argumentation. Engaging in oral argumentation was found to present challenges for some participants in the study due to a perceived lack of scientific content knowledge, insufficient skills of oral argumentation, and the group dynamics present in the classroom. Written argumentation did not present these same challenges in the study, and had the added advantage of providing a context for reflection about NOS ideas, enabling participants to apply and develop their views of NOS more effectively than in oral contexts.

Three task-specific factors were found to mediate the development of participants' views of the examined NOS aspects in the study: (a) argumentation scaffolds, (b) epistemological probes, and (c) consideration of alternative data and explanations. The inclusion of argumentation scaffolds facilitated engagement in argumentation in the study. Used in conjunction with explicit argumentation instruction, these written or verbal prompts were effective in encouraging participants to engage in argumentation. Evidence provided in the chapter suggested that lack of engagement in argumentation in scientific contexts may be influenced by whether participants perceive a need to explain their data, stressing the importance of creating a need for participants to engage in argumentation.

The inclusion of epistemological probes was influential to the development of participants' views of some aspects of NOS in the study. Used in conjunction with explicit NOS instruction, these written or verbal prompts were successful in orienting participants' attention to relevant NOS aspects highlighted in a task, and/or focusing participants' attention on a question designed to draw on their epistemological knowledge or reasoning. The lack of epistemological probes in some tasks in the study hindered participants' abilities to apply their views of NOS to their reasoning during argumentation.

Considering alternative data and explanations influenced participant's engagement in argumentation in the study. Implications drawn from the chapter suggest that the provision of alternative data and explanations forces participants to consider and evaluate multiple sources of data and explanations. Findings from this study support the assertion that, without the provision of alternative data, participants may simply select and evaluate one possible alternative, thus limiting their engagement in argumentation.

Three personal factors were found to mediate the development of participants' views of the examined NOS aspects in the study: (a) perceived previous knowledge about NOS, (b) appreciation of the importance and utility value of

NOS, and (c) durability and persistence of pre-existing beliefs. Perceived previous knowledge about NOS was found to hinder the development of participants' NOS views in the study. Findings suggested that participants who expressed that they already knew about NOS did not have as much incentive to be receptive to learning more about NOS, as they did not initially recognise a need to change their pre-existing views. Conversely, participants who recognised that they did not know a lot about NOS, were more receptive to learning new ideas to clarify and develop their views of NOS, and the development of these participants' views of NOS was relatively more substantial than those participants who held more confidence in their pre-existing views.

Cognitive dissonance was generated for all of the participants at various stages throughout the study as they recognised the deficiencies in many of their NOS views, and sought to find alternative views of NOS congruent with NOS understandings introduced during the course. The administration of the VNOS-C and follow-up interviews was found to provide a context for engaging in reflection about NOS ideas, by forcing participants to explore and clarify their views of NOS.

A lack of appreciation of the importance and utility value of learning about NOS was found to hinder the development of participants' NOS views in the study. Implications drawn from this chapter suggest that participants who fail to recognise the importance of informed understandings of NOS to learning and teaching science may not be motivated to change their pre-existing views. A consideration of these factors suggests that an explicit rationale for learning about

NOS should be provided at the beginning of studies that seek to improve participants' views of NOS.

The durability and persistence of participants' pre-existing beliefs was identified as a third personal factor mediating the development of participants' NOS views in the study. Evidence provided in the chapter suggested that the influence of considerable background life experience for one of the participants in the study limited his ability to discard his previously unchallenged, and largely naïve views of NOS, to accommodate new understandings. The durability of pre-existing views of NOS is highlighted in this instance, which is found to be related to the phenomenon of belief persistence. A consideration of these factors highlighted the importance of making participants explicitly aware of the inadequacies of their pre-existing views of NOS at the commencement of a study, as findings suggested that it cannot be assumed that participants will realise these inadequacies on their own, particularly if their views of NOS have been developed and reinforced over an extended period of time.

9.2 Limitations of the study

The results of this exploratory study are applicable to the five participants selected for investigation in this study. Accordingly, the identification of factors mediating the development of participants' NOS views were determined from data obtained from these five participants. As such, these factors are directly applicable to these participants, and further research is needed to determine whether they apply to other participant groups. In addition, similarly to Abd-El-Khalick and Akerson (2000), information regarding how the identified factors interacted with each other is difficult to determine.

9.3 Conclusion of the study

The findings from this study contribute to the emerging body of research exploring NOS and argumentation. This study has made a unique contribution to the field in that it is the first empirical study that has investigated NOS and argumentation in both scientific and socioscientific contexts, and has implemented explicit NOS and argumentation instruction in both of these contexts.

The importance of enhancing students' and teachers' views of NOS is a central goal of studies conducted in the field of NOS, and this study sought to incorporate explicit NOS and argumentation instruction in a science content course to aid in developing preservice primary teachers' views of NOS. Results indicated that the science content course was effective in enabling four of the five participants' views of NOS to be developed from predominantly less desirable views of NOS to predominantly more desirable views of NOS.

Consistent with previous research (e.g., Abell & Smith, 1994; Akerson et al., 2000, 2006; Gess-Newsome, 2002), all of the participants expressed predominantly limited views of the majority of the examined NOS aspects at the commencement of the study. During the course of the study, participants engaged in a variety of course components specifically designed to facilitate the development of their views of NOS. Many positive changes were evident at the end of the study with four of the five participants expressing partially informed and/or informed views of the majority of the examined NOS aspects. Similar results were reported by Ogunniyi (2006), who examined the effectiveness of an argumentation-based, NOS course situated in a historical context. Thus, the results of this study provide some evidence to support the claim that integrating explicit NOS and argumentation instruction into a science content course incorporating scientific and socioscientific contexts for argumentation, and providing opportunities for participants to apply their views of NOS to their reasoning, may lead to desirable developments in participants' NOS views.

This study critically analysed the effectiveness of various course components designed to facilitate the development of participants' views of NOS, and identified and investigated the various factors that mediated the development of participants' NOS views. A consideration of the implications emerging from these analyses informs the following recommendations for future studies that seek to incorporate explicit NOS and argumentation instruction as a context for learning about NOS.

9.4 Implications and recommendations for future studies

Implications from this study indicate that future studies that aim to incorporate explicit NOS and argumentation instruction as a context for learning about NOS should consider the possible influence of various contextual, task-specific, and personal factors on the development of their participants' views of NOS. As participants may draw on multiple forms of epistemological reasoning in varying contexts, it is important to provide explicit teacher guidance to enable them to apply appropriate epistemological reasoning in given argumentation contexts, particularly scientific contexts. Engaging participants in argumentation in both scientific and socioscientific contexts is recommended, to ensure they are made aware of the differing considerations each type of argument presents. Participants may also need to be provided with specific scientific knowledge to facilitate their engagement in argumentation, particularly in scientific contexts.

Oral and written modes of argumentation can be utilised to provide a context for engaging in argumentation. As various factors such as a perceived lack of scientific content knowledge, insufficient skills of oral argumentation, and group dynamics, may limit participants' engagement in oral argumentation, it is important to provide additional argumentation skills instruction, relevant scientific knowledge support, and group working skills where needed. This study has shown that written modes of argumentation may not present these same challenges, and have the added advantage of providing a context for reflection about NOS ideas. As such, written modes of argumentation may be preferred over oral modes in studies that intend to only utilise one mode of argumentation.

The design of effective course components, or tasks, to facilitate the development of participants' NOS views, is a challenging endeavour. Argumentation scaffolds, used in conjunction with explicit argumentation instruction, may facilitate participants' engagement in argumentation. It is important that tasks are designed to ensure participants recognise the need to explain their data. The provision of alternative data and explanations in tasks also facilitates participants' engagement in argumentation, as it forces them to consider and evaluate more than one data source of perspective. Findings from this study indicate that these task-specific factors may facilitate engagement in argumentation, and enable the application of participants' views of NOS to their reasoning during argumentation.

Results from this study indicate that the utilisation of epistemological probes, in conjunction with explicit NOS instruction, may explicitly draw participants' attention to specific NOS aspects, and enable them to apply their views of NOS to their reasoning during argumentation. As such, the inclusion of epistemological probes are proposed as important components of studies that aim to develop participants' views of NOS.

Findings from this study suggest that personal attributes of the learner are perhaps the single most influential factor mediating the development of NOS views. As such, future studies designed with the aim of improving participants' NOS views should consider the possible influence of factors such as perceived previous knowledge about NOS, appreciation of the importance and usefulness of learning about NOS, and the durability and persistence of pre-existing beliefs. In light of these factors, the following recommendations for future studies are proposed. First, provide opportunities to generate cognitive dissonance from the beginning of the study, to allow participants to recognise the deficiencies in their NOS views, thus allowing them to seek alternative views of NOS congruent with informed views of NOS. Second, provide an explicit rationale to ensure participants are made aware of the importance and utility value of learning about NOS, from the beginning of the study. Stress this rationale throughout the study to maximise opportunities for participants to remain motivated to learn about NOS.

Finally, and perhaps most importantly, a consideration of the durability and persistence of pre-existing beliefs, highlights the importance of ensuring participants are made explicitly aware of the inadequacies of their NOS views early in the study, in addition to generating cognitive dissonance. Participants with substantial life experience may not recognise the inadequacies of their pre-existing NOS views, even when evidence is presented that challenges these views.

In conclusion, studies aiming to incorporate explicit NOS and argumentation as a context for developing participants' NOS views, designed according to the above recommendations, may provide an effective context to enable participants to develop their views of NOS. This study has provided some evidence to support this assertion, although further empirical studies are needed to strengthen this claim. In addition, large-scale studies are needed to determine the influence of these types of courses on participants' NOS views in other populations. For example, although this study has provided some evidence to support the incorporation of explicit NOS and argumentation in a science content course to develop preservice primary teachers' NOS views, would this approach be effective with primary, middle and/or high school students? Would the same factors mediate the development of school students' views of NOS? In addition, research is needed to ascertain whether preservice teachers experiencing this type of course actually implement NOS and argumentation instruction in their own classrooms. Although the participants in this study expressed that they had enjoyed learning about NOS and argumentation, the question of whether they would prioritise the implementation of NOS and argumentation instructional approaches in their own classrooms remains an open question.

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APPENDICES

Appendix A - Course topics

The content of the course consisted of 11 topics:

1. Properties of matter: Focuses on the properties of matter. Explores the behaviour of some substances and devise rules for dissolving. Explores patterns that guide dissolving. Discusses solute and solvent, dissociation, insolubility, dissolving. Investigates the types and characteristics of solutions. Discusses the properties of three types of mixtures (including colloids and suspensions). Incorporates two practical activities which examine solubility and separating mixtures.
2. Atoms and molecules: Defines elements, atoms, molecules and compounds. Discusses characteristics of atoms such as size and mass. Discusses common atoms and molecules. Calculates masses. Discusses components of an atom (electrons, protons, and neutrons), their charges and masses. Discusses atomic number, atomic symbol, average atomic mass, isotopes, mass number, and ions. Discusses atomic theory and historical models used to illustrate the structure of an atom.
3. Chemical reactivity: Defines and discusses chemical reactions, reactants and products. Discusses the process of solvation. Defines and discusses anions, cations, salts, inorganic compounds, dissociation, ionic solution, and radicals. Outlines what occurs when two different ionic solutions are mixed. Discusses spectator ions and precipitates. Outlines the signs that a chemical reaction has occured. Incorporates a practical activity which examines chemical reactivity.
4. The electronic structure of atoms and valency: Discusses energy levels of electrons, orbitals, ground state, energy levels, shells. Outlines the rules for assigning electrons to orbitals - discusses Hund’s rule and the Pauli exclusion principle. Outlines the order of energies diagrammatically. Provides the procedure for the electronic build-up of the first 36 elements. Discusses the relationship between the electronic configuration of an

element and the ion/s it can form. Discusses ionisation energy and relates it to atoms which form anions and cations. Introduces the concept of valency. Introduces metals and non-metals. Discusses the valance of common elements.

5. Ions and ionic compounds: Discusses ionic bonding, provides simple examples of swapping of anions and cations. Discusses common ions and complex ions. Discusses the characteristics of ionic bonded compounds. Discusses solubility rules for ionic compounds. Incorporates a practical activity which examines the different forms of a metal.
6. Periodic table: Provides a short history of the periodic table. Discusses general features of the modern periodic table including grouping of elements, main physical and chemical characteristics, history, uses and importance of common elements. Relates the arrangement of elements in columns to their electronic configuration.
7. Acids, alkalies and pH: Defines acids and bases. Discusses characteristics and examples of acids and bases. Defines indicators and pH, and the pH scale. Discusses the chemical reaction between an acid and a base, and neutralisation. Outlines other common reactions of acids and bases. Incorporates a set of six mini practical activities which examine common reactions of acids and bases.
8. Organic chemistry: Discusses covalent bonds using Lewis diagrams. Give examples of compounds. Discusses multiple bonds. Discusses the physical and chemical properties of organic versus inorganic compounds. Outlines the structure of various organic compounds and identifies functional groups giving their physical and chemical properties. Outlines the naming procedure. Discusses how organic compounds can be obtained from natural and synthetic sources. Discusses common reactions between organic compounds. Incorporates a set of three mini practical activities to produce esters, nylon, and slime.
9. Biological materials: Discusses carbohydrates, lipids, proteins (including enzymes), and nucleic acids. Relates to food processing, food additives, and biotechnological issues.

10. Natural materials: Defines natural materials. Discusses natural polymers including cellulose, rubber, silk, crude oil. Outlines the processes of converting natural materials into synthetic materials.
11. Synthetic materials: Defines synthetic (or processed) materials. Discusses synthetic materials such as synthetic polymers (nylon, dacron, teflon, PVC, polystyrene). Investigates the properties of paints, drugs, and cosmetics.

Appendix B - Mixtures, elements and compounds

(Osborne et al., 2004)

Appendix C - Snowmen (Osborne et al., 2004)

This appendix is not available online.
Please consult the hardcopy thesis
available from the QUT Library

Appendix D - Decision making questionnaire (DMQ)

(Bell & Lederman, 2003)

This appendix is not available online.
Please consult the hardcopy thesis
available from the QUT Library

Appendix E - Global warming science brief (Sadler et al., 2004)

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Appendix F - Superconductors survey (Leach et al., 2000)

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Please consult the hardcopy thesis
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Appendix G – VNOS-C questionnaire (Abd-El-Khalick, 1998)

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Appendix H - Final interview questions

1. Did you enjoy the course?
2. Was there anything specific that you liked?
3. Was there anything specific that you disliked?
4. Did you learn about aspects of NOS during the course?
5. Did you enjoy learning about NOS?
6. Did you find learning about NOS useful (to yourself, to teaching science, to learning science)?
7. Did you learn about argumentation during the course?
8. Did you enjoy learning about argumentation?
9. Did you find learning about argumentation useful (to yourself, to teaching science, to learning science)?
10. Did you find learning about NOS and argumentation enhanced or detracted from learning other course content?
11. Would you have enjoyed the course more or less with/without the inclusion of NOS and argumentation?
12. How would you define/describe NOS?
13. Can you think of any specific aspects or instances of NOS you were introduced to during the course?
14. How would you describe scientific argumentation?
15. Can you think of any specific aspects or instances of argumentation you were introduced to during the course?
16. Do you have any questions/comments?

Appendix I - Coding rubrics – VNOS-C (adapted from Abd-El-Khalick, 1998)

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Empirical	No reference to the empirical NOS either explicitly or implicitly.	Recognise that science is empirical and relies on evidence, although may not use the term ‘empirical.’ Indicates that scientific knowledge is ‘solely’ based on tangible, concrete, visible, observable, measurable, or physical facts, data, or evidence to the exclusion of factors such as interpretation and beliefs. May indicate that reliance on facts exonerates science from the burden of subjectivity or social and cultural attributes, such as values and beliefs, which are commonly associated with religion and philosophy. Science uses observations, facts, or evidence to ‘prove’ its claims ‘right’ or ‘wrong.’ Observable evidence has the sole role in adjudicating between scientific claims. Absolute ‘truths’ could be obtained through the use of physical evidence. Cannot distinguish science from other types of knowledge.	Does not explicitly state that scientific knowledge is influenced by human assumptions and previous knowledge, but relies on observable evidence. Scientific knowledge is grounded in empirical data.	Recognises that scientific knowledge is empirically based and is generally derived from observations of natural phenomena, and that these observations are always influenced by human assumptions and previous knowledge (and are thus theory-laden). Science involves the formulation of ideas (e.g., hypotheses, theories). Evidence is then sought to either support or discount these ideas, which is different to religion. Regarding the term ‘empirical’ these participants do not indicate that tangible data can be used to ‘prove’ scientific claims or that science is based on observations of phenomena to the exclusion of other personal, social or cultural attributes. Even though science relies on evidence and observation, there is much in science that is based on belief, convention, and the non-observable.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Scientific Method	Science is typified by a set of orderly steps and rules or a systematic, structured, rigid, standardised, common, or logical method. Scientists follow a single method during their investigations. All scientists follow the ‘scientific method’ and following it guarantees developing valid knowledge claims about nature.	Don’t believe in a strict, common method but believe scientific investigations only differ in the types and specifics of the ‘experiments’ that scientists conduct. General method – idea, design experiment, do the experiment, collect the results, etc.	Don’t believe that scientists follow “the scientific method” or use an orderly stepwise procedure but still believe in a general, overarching method.	Science has no single method, rather it relies on the creativity of the investigator to find ways to answer his/her question. May explicitly state that they believe that there are discrepancies between the way science is portrayed in scientific reports and the way scientific work is actually conducted. Scientists observe, compare, measure, test, speculate, hypothesise, create ideas and conceptual tools, and construct theories and explanations. Scientific knowledge is gained through multiple methods including descriptive and observational methods.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Aim and general structure of experiments	Does not distinguish between experiments and observations. An experiment involves observation or the collection of data or information.	Participants' characterisations of experiments were mostly general and poorly articulated. No reference is made to the contrived, manipulative or controlled nature of experiments. Do not articulate a clear aim for experiments or merely note that experiments aim to test hypotheses or theories. May comment that an experiment is a test (tool, attempt, project or process) performed in order to prove a proposed theory, or that an experiment is intended to decide whether a hypothesis or theory is true or false (or right or wrong).	Experiments aim to test "the validity or invalidity of a hypothesis" but do not allude to the manipulative or controlled nature of experiments. Experiments are studies "in which experimental units are manipulated by the application of a treatment in order to measure the response of the units to the treatment" but failed to articulate an aim for conducting those experiments.	An experiment is a controlled way to test and manipulate the objects of interest while keeping all other factors the same. When only one factor at a time is changed or manipulated, the observed result can lead the scientist to assume the factor has either a positive or negative or (none) correlation with the outcome. It is the result of an experiment that will lead the scientist to believe his/her theory has or doesn't have validity. Unlike observations, experiments generally involve elements of control and manipulation of, and intervention in the course of the investigated phenomena (dependent and independent variable, etc.)

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Validity of observationally-based disciplines	Believe that experiments are required for the development of scientific knowledge. Observation is not enough to produce valid scientific claims. Do not provide examples to support their view. Experimental method is the only valid method of scientific investigation.	May explicitly state that knowledge obtained from observations are less certain and less trustworthy than knowledge generated from experiments. Do not recognise that several scientific disciplines are mostly based on observation of phenomena.	May express views described in 'informed' but had a naïve understanding of the aim and structure of experiments.	Provides examples to support position. These examples indicate a clear understanding of the fact that several scientific disciplines are observational in nature and that several scientific disciplines are observational in nature and that many powerful scientific theories rest solely on observations. State that manipulative experiments are not required for the development of scientific knowledge.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Theories – tentative nature	Theories do not change. These participants may believe that the original theory might be refined, elaborated or extended, but the theory itself does not change.	Theories do change, but this change is attributed 'solely' to 'new' information, discoveries, or experiments and advances in technology. May not provide an example to support their view, or may provide inadequate example/s to substantiate the position that theories do change with time. Their examples may be historically inaccurate or include ideas or claims that could not be accurately labelled as scientific theories (e.g., the earth is flat example).	As for informed but without the emphasis on advances in 'theory' or reinterpretations. Does not explicitly state that change occurs solely through new information or technologies.	Theories change as new evidence, made possible through advances in 'theory' and technology, is brought to bear on existing theories, or as old evidence is re-interpreted in the light of new theoretical advances or shifts in the directions of established research programs. Theories do change, and other factors play as much a significant role in theory change as do new data and technologies. The advancement of new ideas and theories, social and cultural change, and the role of individuals working 'out of context' may be factors that participants believe contribute to theory change. May or may not provide adequate example/s. Evolution theory and atomic theory may be commonly cited (both of which are mentioned in the VNOS). Other examples which may be cited include shift to plate tectonics, rejection of spontaneous generation, and shift from geocentric to heliocentric cosmology.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Well supported nature of theories	Believe that scientific theories are "just a theory" in the vernacular sense of the word; a guess or someone's idea about what occurred or might occur	Others may believe that scientific theories are still speculation and can be altered because there is still not enough evidence for them.	Some appreciation of the supported nature of theories and a recognition that they have evidence behind them but not an informed understanding.	Scientific theories are well-established, highly substantiated, elaborate, internally consistent systems of explanations. Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. Scientific theories are concepts that have considerable evidence behind them, and have endured attempts to disprove them.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Theories – explanatory function	Incorrect view of the explanatory function of theories	No recognition of the explanatory function of theories	Recognise the explanatory function of theories. May indicate that theories help us explain or are the best current explanations for natural phenomena. May also indicate that we learn theories because mankind is curious, or that theories serve as building blocks or starting points for expanding our knowledge and understanding. Some may indicate that learning scientific theories help us to understand things and they act as a stepping stone for new knowledge. But further probing may indicate that they implied a "knowledge built on itself" view. Did not recognise the aspects such as generating research problems or triggering investigations described in informed.	Appreciate the significant role that theories play as general guiding frameworks for scientific investigation. They play a major role in generating research problems and guiding future investigations. Investigation can be triggered by scientific theories.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Difference between scientific theories and laws. Relationship between theories and laws.	Hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. May indicate that scientific theories are less valid or supported than scientific laws or that theories are merely precursors to scientific laws. May explicitly indicate that theories become laws when "proven" true. May indicate that theories and laws differ because laws are "proven" to be correct or true while theories are not. May indicate that theories and laws differ because laws are proven to be true beyond reasonable doubt, and theories are able to change and be proven false at any time. Scientific laws are absolute and certain. Through repeated testing laws can be "proven" true. Provide inaccurate examples.	May have some correct definitions of theory or law but does not understand the difference between the two. May realise that laws cannot be proven, but still believe that laws are 'true.' May indicate that laws have not been disproven.	General understanding of the definitions of laws and theories. A law is something that holds true while describing what is happening. Whereas a theory is why that happens. A law is something that happens and a theory explains why it happens. May provide adequate examples of scientific laws Theories and laws are different types of knowledge, but still holds the view that theories become laws or that laws are proven.	Scientific laws are statements or descriptions of the relationships among observable phenomena. Scientific theories are inferred explanations for observable phenomena or regularities in those phenomena. Provides adequate examples. Recognise that theories and laws are different kinds of knowledge and one can not become the other. Provide accurate examples.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Ranking theories and laws	Rank laws above theories. Laws have a higher status than theories.			Recognise that theories are as legitimate a product of science as laws. Realise that scientists do not usually formulate theories in the hope that some day they would acquire the status of "laws."

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Tentative - general and theories and laws	Do not seem to believe that scientific knowledge is tentative. Science is different from other disciplines of inquiry in that scientific knowledge is definitive, correct, or "proven" true. Laws are absolute and do not change. Theories do not change. Hierarchical relationship exists between theories and laws. Theories are just theories and have yet to attain the status of "law" or "proven" fact.	Theories change, laws are fixed.	All scientific knowledge changes, no reasons given, or only new observations given as a reason.	Scientific knowledge, though reliable, is at best tentative and 'never' absolute or certain. This knowledge, including facts, theories and laws, is subject to change. Although scientific knowledge is highly reliable and durable. Laws and theories change.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Creative and imaginative	Scientists do not use creativity and imagination in their investigations. Science is a lifeless, rational, and orderly activity based solely on empirical evidence. Conclusions should be based solely on the data.	Scientists use creativity and imagination but such use is not desirable. Creativity and imagination are often used to bias or "distort" investigations in order to fit scientists' agendas to publish and/or secure funding. May or may not provide examples or provides examples derived from everyday life situations. Scientists only use creativity and imagination in the planning and design stages. Using imagination and creativity in data collection, data interpretation or in deriving conclusions would result in "incorrect" findings. Scientists use creativity and imagination in all stages of investigation with the exclusion of data collection.	Creativity and imagination are needed in all stages of scientific investigation, but may not use the term "creativity and imagination" to refer to the 'invention' of explanations, models or theoretical entities. Rather used the terms to refer to "resourcefulness, skilfulness, or cleverness. " May equate creativity and imagination with being open-minded, considering all the possibilities, and examining a situation from "all the angles." These views may be implicit. No explicit use of 'invention.' Provides adequate examples derived from science or scientific practice.	Imagination and creativity are need in scientific investigation and permeate all stages of scientific investigation. Use of the term "creativity and imagination" refers to the 'invention' of explanations, models or theoretical entities. Provides appropriate examples derived from science or scientific practice. Recognises the empirical NOS but nonetheless the development of scientific knowledge involves human imagination and creativity. Science involves the invention of explanations and theoretical entities. Creativity influences the interpretation of data.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Social and cultural	Science is universal. Social and cultural factors limited to differences in terminology or units of measurement.	Recognises the influence of social and cultural factors but implies that these influences are negative.	Recognises influences of political, economical and ethical issues on 'what' scientists investigate. Social and cultural factors may influence the rate at which scientific truths are recognised.	Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy and religion. Provides adequate examples. Recognise social and cultural influences on 'how' science is practiced.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Inference and theoretical entities in science – atoms	Believe that scientists are certain about atomic structure because high-powered electron microscopes were used to determine what an atom "looks" like. They believe that scientists have actually "seen" atoms, demonstrating a lack of understanding of the inferential nature of the "atom" and of the distinction between observation and inference. Scientific knowledge comes directly from observations.	Believe that scientists are certain about the structure of the atom, but do not indicate a belief that atoms were or could be "seen" or an understanding of the inferential nature of the concept of the atom or the kind of evidence used to infer its structure. Alternately they believe that scientists are certain about atomic structure, but explicated unfamiliarity with the relevant evidence, but expressed a faith in scientists and the efforts that were expended to arrive at the present structure of the atom.	Believe that scientists are uncertain about the structure of the atom but cannot accurately explain why. They fail to recognise the relevance of indirect evidence and inference to arriving at a structure for the atom (they can't explain how scientists can come up with an elaborate structure if they haven't directly seen one). Don't articulate a fully informed view? Recognise that atoms are not directly observable. Uncertain about whether structure of the atom is determined by direct observations or not.	Atoms cannot be directly observed and that only indirect evidence is used to determine the structure of an atom. May indicate that the structure of an atom is a model intended to explain observations of the "behaviour" and/or "properties" of atoms in reaction to various experimental manipulations. Recognise that scientific models are not copies of reality.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Inference and theoretical entities in science – species	Scientists are certain about the notion of species with reasons cited including – scientists use a variety of observational evidence, especially DNA sequencing, to determine species membership. Wolf/dog example – such cases are only mistakes in classifying certain organisms, with advances in technology, especially DNA sequencing, scientists will be able to "figure out" such mistakes. Scientific knowledge comes directly from observations.	Scientists established the characterisation of species through conducting experiments such as cross-breeding various organisms. Such experiments confer certainty on the notion of species. Circular logic typified the responses of some participants who attempted to defend this position. They noted that scientists are certain that a species is a group of similar organisms that interbreed and produce fertile offspring because only organisms of the same species can interbreed and produce fertile offspring. Wolf/dog example – may respond that the lines scientists draw among various species are not clear cut, variations exist in nature, and it is not possible to "get it right" all the time.	Scientists are not certain about the characterisation of species, with reasons including – there are many disagreements among scientists about the construct itself, variations among organisms abound and grey areas and exceptions that defy classification and blur the lines between certain species, according to evolutionary theory scientists could not be certain about the notion of species since speciation is an ongoing process. Responses in this category nonetheless had no indications that "species" is a human construct or the result of a man-made attempt to classify organisms.	"Species" is a human construct, or part of a man-made classification system intended to help scientists bring some order to the enormous variety between and among various groups of organisms observed in nature. Like other classification systems, the concept of "species" has some merits. For instance, it helps scientists classify, make sense of the relationships between, and communicate about various organisms. But like all other classification systems, the concept of "species" has limitations and leaves much to be desired. Sharp lines are often difficult to draw among certain groups of organisms that seem to simultaneously belong to more than one species. Such groups of organisms seem to belong to grey areas that span the terrain between the blurred lines that often run between closely related groups of organisms.

Aspect of NOS	Naïve view	Limited view	Partially informed view	Informed view
Subjective and theory-laden	Attributed the controversy to the scarcity of the available "data," - many seemed to equate data relevant to the extinction issue with "seeing what has happened." They misconceive the meaning of "data" or "evidence" and also misunderstood the logic of hypothesis testing. Scientists were not around 65 million years ago to witness it and could not go back in time to "see" what happened, scientists can only produce "theories" (in the vernacular sense) about what happened. Science is objective and value-free. Disagreements are due to lack of data.	Many participants may use the term "data" adequately to refer to artifacts left by either hypothesized event. Some of the participants may indicate that both hypotheses are consistent with the available data. Many noted that there is simply not enough or conclusive evidence to champion one hypothesis over the other. The obvious consequence of this present "lack of data" is that the controversy would be resolved if there were "enough" or "complete" data or if such data is obtained in the future. As such, these participants failed to recognize that factors other than "data" might play an important role in generating and supporting scientific claims. They did not seem to understand that data need to be interpreted from within certain theoretical frameworks to acquire any significance as supportive of one scientific claim or another. Some participants indicated that it is possible for scientists to reach different conclusions starting from the same data set because of imagination and creativity. However, these participants did not seem to believe that imagination and creativity are integral to scientists' work. Rather, they indicated that data are scarce and scientists are forced to fill in the gaps using their imagination and creativity. Again, the implication being that if there were "enough data" the controversy would be non-existent since scientists need only refer to the data to draw their conclusions. Use of imagination and creativity may even be referred to as undesirable. Some participants may also refer to factors such as money, prestige, ego, and the race to publish as possible causes for the controversy. They may state that such factors are hindrances to the "real" search for knowledge and cooperation among scientists. Some participants indicated that factors such as fame and scientists' egos, and the race to secure funds for research are behind the extinction controversy. These participants seemed to understand that science is another human activity and is thus infused with human attributes characteristic of such activities including competitiveness, and the thirst for power, fame, and other personal interests. But often quotes taken from these participants appeared to convey a "negative" message – that competitiveness, etc., are not only foreign to science but also undesirable, and these messages were substantiated by interview.	Participants noted that scientists arrive at different conclusions because they interpret the data differently, but did not explicate any reasons as to why different scientists would interpret the same data differently. Discussion of subjectivity focuses on personal subjectivity.	Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, previous knowledge, training, experiences, and expectations influence their work. All these background factors form a mind-set that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret their observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge. Subjectivity due to professional knowledge, experiences and mindset. Role of discussion/peer review on the reaching of consensus regarding conclusions.

Appendix J – Coding rubrics – Superconductors survey (adapted from Ryder & Leach, 2000)

Data focused -

Survey section	Data focused views (responses reflect a belief in the primacy of data in the data interpretation context)
Part 1 – Express an opinion	D – It is unclear which group has drawn the best line, but if enough data are collected it should be possible to decide between the two lines.
Part 2	C – Collect more data in order to prove beyond reasonable doubt which group is correct (It is certainly the case that gathering more data may help the scientists to decide between the two interpretations, but the emphasis is on the quantity rather than the quality of data. No recognition that the ideas contained in the models are also relevant to judgments between these two interpretations. What assumptions and approximations are made about the superconducting material in the development of each theoretical model? Are these assumptions and approximations reasonable? …No recognition that the ideas contained within the models are important and need to be considered. Thus this response is not wrong, but is certainly limited). D – Reduce the errors in the measurements in order to prove beyond reasonable doubt that the LIS model or the COAST model gives the best interpretation.
Part 3	DidaScO – Draw a line joining each of the points. We are confident about each measurement, so this is the best approach ('the data are accurate, so we should just join the points'). TESME – Use a computer to generate the best curved line through the data points. This is the best approach (Students may choose this option as they see the computer as the 'final' part of the data interpretation process. This response is not necessarily wrong, but limited. Computers are used to generate lines of best fit through data points by applying numerical algorithms such as the 'method of least squares.' Computers are also used to graph the relationship between two variables as predicted by a theoretical model, and perhaps to compare the predicted relationship with that indicated by the data. However, these are only a few steps in the data interpretation process. The computer in itself cannot make judgments concerning the validity of the ideas behind competing theoretical models. It is this aspect of the data interpretation process which is missing from this response). ('the data are accurate, so a computer can be used to process the data –without reference to underlying models').

Relativist focused -

Survey section	Relativist views (responses reflect the view that there are limited grounds for assessing the truth of knowledge claims in science)
Part 1	E – Both interpretations are acceptable. It is not possible to find out which interpretation is better.
Part 2	H – The scientists should accept that there can be more than one interpretation of this data. There is no way of finding out which interpretation is the correct one.
Part 3	ROMA – There is no way of knowing which is the best way to join the data points. It is up to individual scientists to make up their own minds. (But interview responses indicated that this closed response may not have been communicated as intended. May reveal a data-focused view during interview, and thus an overestimate of relativist responses).

Model focused -

Survey section	**Model focused views (response emphasising models)**
Part 1	C – It is unclear which group has drawn the best line. You can only decide which interpretation is better by looking at the details of the LIS and COAST models.
Part 2	E – It will only be possible to decide what to do next by considering the models proposed by the LIS and COAST groups. (A significant proportion of respondents may feel it is 'inappropriate' to consider models when interpreting the data, or they were 'unsure' whether it was appropriate. 'Unsure' suggests that many students may have been unclear about the nature of the models described in the survey. May associate 'model' directly with the line through the data points, or may focus on the 'model' as representing the relationship between the resistance and temperature, without any apparent recognition that these models would typically include a theoretical description of why the resistance changes with temperature. Many students will demonstrate during the interview that the meaning of models in the context of the survey had not communicated as intended. Analysis of the closed responses may give an overestimate of the proportion of students holding a model-focused view).
Part 3	BREM – Consider which model could best be used to explain this data set. Once the best model has been agreed upon, a line can then be drawn through the data points ('data treatment should be informed by underlying models').