EXPLORING NEW ZEALAND YEAR 11 STUDENTS' UNDERSTANDING OF NATURE OF SCIENCE CONCEPTS

BY
BLAIR DANIEL NORTHCOTT

A thesis
submitted to the Victoria University of Wellington
in fulfilment of the requirements for the degree of
Doctor of Philosophy

Victoria University of Wellington
2014

ABSTRACT

Nature of Science (NOS) is a core part of science education. Extensive effort has gone into establishing educationally appropriate NOS tenets, teaching practices and assessments tools. However, while previous research has identified the importance of prior knowledge in science education, there is limited research that investigates students' prior knowledge and beliefs about NOS. This information is critical in identifying what teachers need to target in order develop informed NOS beliefs amongst students. In this study the NOS beliefs of year 11 secondary school students in New Zealand were explored using a mixed methods approach. Factor analysis of the students' (N=502) NOS questionnaire responses revealed that students' conceptions of NOS differed from the constructs identified in the NOS literature. Coding of the purposively selected sample of student interviews (n=22) revealed a naïve realist model of science was common. This model along with the alternative constructs provided insights into students' NOS conceptions. The findings were used to develop a model that could help teachers' better identify explicit and implicit teaching practices to help students develop more appropriate NOS models.

ACKNOWLEDGMENTS

This thesis has only been completed due to the kind patience, support and help of many wonderful people.

Thank you to my parents, Bruce and Kathy, for their support, encouragement and help throughout this endeavour. I am grateful to them and my friends and family for nurturing my curiosity and passion for science and education.

Thank you to my supervisors, Dr. Matt McCrudden and Dr. Azra Moeed, for their confidence in me, their guidance throughout this process and their valiant struggle to keep me on task. Thank you also to the colleagues and support staff of VUW who helped me along the way.

Thank you to the students, schools and teachers who all took part in this study and all the wonderful educators and students who I have had the pleasure to work with. You have all contributed greatly to my continuing growth as an educator and a student.

Finally, I would like to thank my lovely and patient wife, Tara, and our wonderful son, Brendan. They are the added bonus of this great journey that I am forever grateful for.

Dedicated to the two Michaels who have shaped each end of my life…

Michael John O'Donoghue

(1918 – 2006)

Brendan Michael Northcott

(2013 -   )

A person substantially determines who he is or what he becomes in the process of living

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - INTRODUCTION

"*Science is our best defence against believing what we want to*." Ian Stewart

The Nature of Science (NOS) is the study of the epistemology of science; the practices, beliefs, assumptions and justifications scientists use to construct, develop and advance scientific knowledge (Crowther, Lederman, & Lederman, 2005; Hofer, 2000; Lederman, 1992; Sandoval, 2005). The details of NOS are a subject of considerable debate; historians, philosophers and sociologists of science hold a range of views reflective of their fields of study, whereas scientists hold views about NOS that reflect their personal experience in science (Abd-El-Khalick, Bell, & Lederman, 1998; Alters, 1997; Schraw & Sinatra, 2004). Despite the intricate complexity of the philosophy that underlies scientific issues (Eflin, Glennan, & Reisch, 1999), the importance of NOS as a means to develop a skilled and informed citizenry is an essential part of modern science education (Driver, Leach, Millar, & Scott, 1996; Ford, 2008; McClune & Jarman, 2010; Sandoval & Reiser, 2004). As a result accessible, fundamental, non-controversial aspects of NOS have become core parts of science education curricula in countries all around the world (Hipkins, 2012; Lederman & Lederman, 2004a; Matthews, 1998; McComas & Olsen, 1998; Ministry of Education, 2007).

Having taught in a number of countries with NOS focussed science programs, I have become increasingly aware of the impact students' beliefs about science have on their learning. Prompted by the image of science described by Jack Cohen and Ian Stewart in their books (Cohen & Stewart, 1995; Pratchett, Stewart, & Cohen, 2002, 2003, 2005; Stewart & Cohen, 1997), I began to focus my lessons on challenging students' beliefs about NOS, encouraging them to see science as an active and vibrant construction of knowledge rather than as a dull and dry accumulation of absolute facts (Solomon & Thomas, 1999). This change in perception had a significant effect on my students' interest in and motivation for learning about science and I began to explore more about the ways NOS could enhance science education.

On returning to New Zealand to further my studies I wanted to know what impact almost two decades of inclusion of NOS in the science curriculum had had on New Zealand students' beliefs about science. While research has established that many

New Zealand teachers viewed the NOS strand as pages to be turned over (Barker, 2009; Loveless & Barker, 2000) and taught aspects of NOS in a mechanistic manner (Hume & Coll, 2008), little research existed on New Zealand students' understanding of NOS (Jones & Baker, 2005). As successful science instruction is dependent on integrating students' prior knowledge and beliefs with new knowledge (Freyberg & Osborne, 2001), the lack of research into students' intuitive understanding of NOS appeared to be a major hindrance in efforts to develop sound NOS understanding in New Zealand. The present study aimed to explore the way students' prior knowledge and intuitive beliefs about science affected their understanding of NOS concepts. The study used a sequential mixed methods approach to sample 532 year 11 students with a screening questionnaire, and then selected 22 participants to interview based on the questionnaire data. A thematic analysis was conducted to generate a common model that could be used to understand the interpretations and beliefs of the students.

Chapter two reviews the role of NOS in national and international curricula and goes on to describe the core educational NOS concepts routinely examined in the literature in the form of NOS tenets and found in national curricula. The literature review then examines the tools and techniques used to asses NOS beliefs and development and reviews research examining factors that influence NOS beliefs amongst teachers and students up until the time of the study in early 2011. From the literature review the need to understand students' innate beliefs about NOS is identified as a requirement to helping them construct appropriate NOS beliefs.

Chapter three gives a brief overview of the study and identifies the initial research questions. Three overlapping theoretical lenses are identified as educational constructivism, instrumentalist pragmatism and NOS, and their role in defining the study and guiding the data analysis is described. The sequential mixed method design is then detailed; the parameters of the study are established and the study participants are described. Finally, the steps involved in the collection and sequential analysis of the quantitative and qualitative data are clarified along with the final mixed analysis procedure.

Chapter four briefly outlines the researchers' decision to develop a study specific NOS questionnaire when no viable tool could be identified. Chapters five through eight detail the development of this questionnaire. Chapter five and six describe the method and results of the initial pilot study and the changes recommended to the tool by the focus group. Chapter seven and eight then detail the second pilot study and the face validity assessments NOS experts carried out on the finalised version of the questionnaire.

Chapter nine begins the study proper, detailing the questionnaire administration procedure and detailing the statistical analysis procedures used. The theoretical NOS model derived from the NOS literature is introduced and the goodness of fit parameters are defined for this study. Chapter 10 describes the detailed statistical analysis of the questionnaire results. Following descriptive statistics of the data, confirmatory factor analysis (CFA) is used to test the theoretical NOS model against goodness of fit parameters. As these parameters were poor, the study details the researchers' attempt to find an improved model through use of Exploratory Factor Analysis (EFA) on half the data and the subsequent testing of those models with CFA on the other half. From the potential factor solutions that produced improved goodness of fit parameters, the researcher focussed on a four-factor solution as the most parsimonious model and attempted to identify the constructs underlying the model. Using this construct model, representative students were identified to take part in the interviews.

Chapter 11 describes the selection of the interview participants and details the interview and coding procedures. The coding categories then summarise the data derived from the interview questions examining whether representative sample groups elicit similar responses and if the qualitative data supports the alternative construct model. The description of science that emerged from the students was a naïve realist view which did not on the surface account for the informed responses detected in the quantitative data.

Through the mixed analysis, chapter 12 shows the way the researcher sought to find symmetry between the qualitative and quantitative data sets. By examining the interview data alongside the questionnaire data the researcher was able to describe the ways students could use their naive realist beliefs to rationalise informed responses. The findings of the qualitative analysis and quantitative analysis are shown to be mutually reinforcing and collectively provide an enriched understanding of the way students understand science.

Finally, in chapter 13 the researcher uses the data to answer the initial research questions and addresses the emergent research questions. The researcher also proposes a naïve realist model that unifies the qualitative and quantitative data gathered from the students. The limitations of the study are discussed and suggestions are made to resolve these issues in future studies. Implications for practice and research methodology are described and the research identifies potentially promising future research avenues.

This study set out to explore New Zealand students' multidimensional NOS beliefs using a mixed methods approach; however the qualitative and quantitative data did not support this research assumption. The naïve model of NOS that the researcher identified in this study may provide a more valuable way to assess students' thinking about NOS and identifies students' perceptions of law, theory and fact as key obstacles to developing appropriate NOS beliefs.

CHAPTER 2 – LITERATURE REVIEW

I would teach how science works as much as I would teach what science knows. I would assert (given that essentially, everyone will learn to read) that science literacy is the most important kind of literacy they can take into the 21st century. I would undervalue grades based on knowing things and find ways to reward curiosity. In the end, it's the people who are curious who change the world.

Neil deGrasse Tyson

2.1. NOS in the Curricula

Since the early twentieth century educators have promoted the understanding of NOS as an important goal for science education (Lederman, McComas, & Matthews, 1998; Trefil, 2008). Early educators such as Dewey initially focussed on ensuring students going on to higher levels of science education understood the epistemology of science (Trefil, 2008) Today, the increasing influence of science and technology on society has meant that the focus has shifted towards ensuring all citizens understand NOS so that everyone can be intelligent and critical consumers of scientific information (Barker, 2004; McComas, Almazroa, & Matthews, 1998; M.U. Smith & Scharmann, 1999).

In the modern world, the avalanche of scientific and pseudo-scientific information alongside common misconceptions about the way science works leads many people to hold misinformed and distorted views of what is and is not science. Consequently, many people have distorted views of science that leads them to hold unsound, illogical and unreasonable beliefs about the natural world (Driver et al., 1996; McComas et al., 1998). The volume of scientific data and the misunderstandings about the certainty of scientific knowledge means that for many socio-scientific issues, such as genetically modified foods and climate change, the public response ranges from blissful ignorance or misinformed opinion with only some parts of the population attempting to address the issue through intelligent engagement (Barker, 2004). In response to this situation science educators have identified NOS education as a way to generate a more realistic image of science that can:

- increase interest in future science related careers (Ryder, Leach, & Driver, 1999);
- ensure citizens are able to take an active and informed part in socio-scientific debates (Driver et al., 1996; Trefil, 2008);
- provide citizens with the scientific literacy skills needed to manage their lives in the modern world (Barker, 2004; Driver, et al., 1996);
- allow citizens to rationally identify valid scientific claims (Ford, 2008);
- allow citizens to critically evaluate socio-scientific information in the media (McClune & Jarman, 2010);
- improve economic output by ensuring the workforce is skilled and proficient at handling and analysing scientific information (Austin, 1997; Driver et al., 1996);
- help citizens recognise and appreciate the achievements of science and the impacts it has on the quality of their lives (Driver, et al., 1996).

In New Zealand interest in NOS arose in the 1980's when people began to question whether the highly prescriptive science curriculum, derived from the Thomas Report of 1944, was effective in producing the scientifically literate population New Zealand would need to compete in an increasingly scientific and technologically dominated age (Austin, 1997). The 1991 Ministry of Research, Science and Technology (MORST) report that revealed New Zealanders held an overly negative image of science further supported this (Matthews, 1995). Only 10% of those sampled had the minimum understanding required to be considered scientifically literate, and of that, only 3% professed an interest in science (Matthews, 1995). The curriculum prior to 1993 had focused on students who were intending to enter careers in science or medicine. From 1993, the science curriculum has included explicit NOS achievement aims intended to increase all students' understandings of science to improve public scientific literacy skills and to enhance New Zealand's science-based economic output (Austin, 1997; R. Baker, 1997; Coll, Dahsah, & Faikhamta, 2010).

Since its initial inclusion in *Science in the New Zealand Curriculum (SiNZC)* in 1993, the NOS strand has continued to assume greater importance (Hume, Coco, & Green, 2007), linking to the wider objectives of vision, values and principles laid out in the *New Zealand Curriculum* (Ministry of Education, 2007). The spiral design of the NOS strand in the NZC introduces age-appropriate NOS concepts to students and develops these ideas through subsequent years of schooling. This curriculum document presents an image of NOS that, like its predecessor, is consistent with the broad consensus found in other national curricula (McComas & Olsen, 1998; Ministry of Education, 1997), contains objectives consistent with the core NOS concepts identified in the next section, and is consistent with the constructivist theory that underlies New Zealand educational practice (B. Bell, 2005; Matthews, 1995). The NOS strand itself represents a unifying construct within the broader term *scientific literacy* which educators use to broadly include the nature, aims, and general limitations of science, along with the understanding of some of the more universal scientific ideas of the age (Laugksch, 1999). While both the most important scientific ideas and the limitations of science change with advancing scientific knowledge and technical ability, NOS provides students and future scientific consumers with a framework by which to assess new claims. The following section outlines the key NOS concepts that are purported to be crucial in establishing such a framework.

2.2. NOS Concepts

While consensus has developed about the benefits of NOS for science education, exactly which concepts should be included has been a more contentious issue (Alters, 1997; R. Baker, 1997; Eflin et al., 1999; Matthews, 1998; M.U. Smith, Lederman, Bell, McComas, & Clough, 1997; Solomon & Thomas, 1999). Historians, philosophers, sociologists and scientists continue to disagree on specific issues about what constitutes scientific knowledge, how new knowledge is generated and validated and what happens when established ideas are overturned (Abd-El-Khalick et al., 1998; Alters, 1997; Eflin et al., 1999; Monk, 2006; Schwartz & Lederman, 2008; Vamvakeros, Pavlatou, & Spyrellis, 2010; Wong & Hodson, 2009). This diversity of views represents the variety of lenses' through which each group views science; historians focus on paradigm shifts whereas philosophers focus on validity and justification issues, sociologists focus on social interactions and power relationships whereas the views of scientists' vary based on their field of research and personal experience (Schwartz & Lederman, 2008).

Despite debate in educational literature about what should be taught (Alters, 1997; M. U. Smith, et al., 1997) a consensus of core NOS concepts has emerged (Lederman & Lederman, 2004a; McComas & Olsen, 1998; J. Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003) These concepts focus on maintaining the fine balance between depth and relevance needed to ensure that students are able to develop an adequate level of scientific literacy. If NOS concepts are oversimplified, they do not aid students in making valid reflective judgements, but if explored too deeply, the complex and nuanced nature of the arguments and ideas are too difficult for students to understand and apply. To address this, education researchers have identified concepts appropriate for use with school students that are non-controversial to NOS experts but which can be used as a framework for evaluating scientific information (Akerson & Donnelly, 2009; Barker, 2006; Lederman & Lederman, 2004a; Matthews, 1998; McComas, 2004; J. Osborne et al., 2003).

The most prominent NOS framework is that developed by Lederman and colleagues for use with the Views of Nature of Science (VNOS) questionnaire (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). It consists of five core tenets about the way science works and three core terms that students should be able to distinguish and define. It is used by many researchers to assess NOS understanding, responses that are highly consistent with the concepts and definitions identified by Lederman are considered to reflect an informed understanding of NOS (Abd-El-Khalick, 2005; Akerson, Buzzelli, & Donnelly, 2008; Dogan & Abd-El-Khalick, 2008; Irez, 2006). The following descriptions of the core concepts and terms are adapted from Lederman and Lederman (2004b).

CORE TENETS

1. Science is based on empirical evidence. All scientific knowledge is, at least partially, based on observations about the natural world. Explanations must be checked against what actually occurs in nature.

2. Science requires human imagination and creativity. Scientists must use creativity to form their explanations, develop their ideas and models, and to devise ways to test their predictions.

3. Science is theory-laden. Scientists' beliefs, theories, prior knowledge and experiences all shape the problems they investigate, the observations they make and the way they interpret data.

4. Science is socially and culturally embedded. Science affects and is affected by society and culture through such things as social values, political agendas, socioeconomic factors and religious beliefs.

5. Scientific knowledge is durable but tentative. Scientific knowledge represents human constructed interpretations and explanations of phenomena about the natural world. It is never absolute or certain about its claims as new interpretations or new evidence, made available through new discoveries or improved technology, can change its descriptions and explanations.

CORE TERMS

1. Observation and inference. Observations are descriptive statements about natural phenomena obtained via the senses or detection equipment, which can be easily agreed upon by multiple observers. Inferences are statements about phenomena that cannot be directly accessed by the senses.

2. Scientific laws and theories. Scientific laws are descriptive statements about the relationships between observable phenomena. Scientific theories are inferred explanations about phenomena. Theories do not mature into laws; rather, the two represent distinct types of scientific knowledge.

3. The scientific method. The scientific method is not a universal method used by all scientists, instead it refers to the diverse but related group of inquiry skills that help identify valid questions, determine the appropriate strategies to investigate the question, and inform the researcher on how to examine and interpret data about the phenomena.

These tenets have been criticised for producing an image of NOS that teachers could present in an overly decontextualised way (Osborne et al., 2003) and that are too broad to be epistemologically sound (Elby & Hammer, 2001). Epistemology models have been proposed as a way to represent the change in students' beliefs about knowledge claims. In the initial stages students are seen to view knowledge claims as authoritative and unproblematic. They then pass through a relativist stage where all knowledge claims are equally valid and eventually develop an understanding that knowledge is interpretive and needs to be evaluated against appropriate criteria (Borda, Burgess, Plog, DeKalb & Luce, 2009). But epistemology studies and models indicate that epistemology trajectories do not fully develop until students have graduated from college (Baxter Magolda, 2004; Elby & Hammer, 2001; Eflin, et al., 1999; Hofer, 2006; Kuhn & Weinstock, 2002; Muis, Bendixen, & Haerle, 2006). NOS is closely related to epistemology, as it examines the development and justification of scientific knowledge claims (Borda, et al., 2009) however, the tenets proposed are aimed at providing a relatively robust set of learning goals for educators that when implemented can provide students with acceptable level of scientific literacy (Lederman, McComas, et al., 1998; Solomon & Thomas, 1999; M. U. Smith, et al 1997) which can be used as a framework in assessing whether particular opinions are scientifically sound (McComas, et al., 1998). This is in lieu of advanced epistemological understanding which is rare among students at a high school level. By comparison, NOS studies by Akerson and colleagues that used the NOS tenets proposed with age appropriate teaching interventions have shown that young children can learn NOS concepts which can be used to assess knowledge claims (Akerson & Abd-El-Khalick, 2003; Akerson & Abd-El-Khalick, 2005; Akerson, Buzzelli, & Donnelly, 2010; Akerson & Donnelly, 2009; Akerson & Volrich, 2006; Quigley, Pongsanon, & Akerson, 2010).

While this declarative knowledge is not the robust epistemology of highly experienced and educated scientists, it can provide students with guiding frameworks by which to assess and judge scientific information. In Akerson's studies even young students could learn these generalised NOS tenets despite being at an age that epistemology models identify with simple authoritative beliefs about knowledge (Hofer, 2000). Knowledge of these NOS tenets, when introduced in a pedagogically appropriate order, does not require students to hold advanced epistemology beliefs which are beyond their normal developmental trajectory. Rather these ideas set out a pedagogically appropriate foundation which students can use as a foundation to develop their understanding of the powers and limitations of scientific knowledge. An educational NOS program must lay an appropriate foundation to help guide students away from their authoritative beliefs about knowledge if it is to achieve its end goal of a general populace capable of making appropriate evaluations about scientific knowledge claims. While NOS tenets can be taught as decontextualised statements (Clough & Olson, 2008) NOS-specific pedagogical approaches benefit students understanding of science (Akerson & Abd-El-Khalick, 2003; Schwartz & Lederman, 2002).

The tenets Lederman identifies are consistent with the tenets identified by McComas and Olsen (1998) in their meta-analysis of world science curricula as representing the dominant emergent NOS concepts present. The tenets are also consistent with the results of the Delphi study conducted by Osborne et al. (2003) (see Table 2.1). In their study, Osborne and colleagues asked 23 international experts from education, history, philosophy and sociology of science fields along with acknowledged expert scientists to identify the key concepts they considered important for students to learn. The overall consensus of these results indicates the relative agreement that has emerged amongst experts within science education about what core, fundamental principles NOS education should provide to students. While the concepts can be simplified as discrete declarative tenets, the concepts they reflect have contextual variations and should not be considered to be dogmatic truths; they represent a practical and achievable framework that students can use to make sound judgements about the validity of scientific knowledge claims they encounter. Through this study the concept will be used when addressing a broad NOS idea while tenet refers to the specific statements made about a given concept.

Table 2.1

Comparison table of key NOS tenets: adapted from Osborne et al., (2003)

Osborne et al (2003)	McComas & Olsen (1998)
Science and certainty.	Scientific knowledge is tentative.
	Changes in science occur gradually.
Science and questioning.	
	Science is an attempt to explain phenomena.
Historical development of scientific knowledge.	Scientific ideas have been affected by their social and historical milieu.
Cooperation and collaboration in the development of scientific knowledge.	Science is part of social tradition.
	Science has global implications.
Science and technology.	Science has played an important role in technology.
Creativity.	
	Scientists are creative.
Analysis and interpretation of data.	
Scientific method and critical testing.	Science relies on empirical evidence.
Hypothesis and prediction.	Scientists require replicability and truthful reporting.
Diversity of scientific thinking.	
	New knowledge must be reported clearly and openly.

These tenets collectively define what Campbell (1998) identifies as a constructivist view of NOS. In this view, reality exists independently of the observer but our knowledge of it must be constructed as any objective measure influenced by the way we interpret it. The appropriateness of a scientific idea is then solely based on how closely its useful predictions fit the impressions of reality. This is counterpointed by the realist or positivist view of science which also recognises a reality independent of the observer. However, in this view reality can be directly experienced by everyone in precisely the same way limiting the role of human interpretation in knowledge generation. Science educators view the NOS tenets identified above as being fundamental ideas to shifting students' beliefs about science from realist beliefs, to ones more consistent with constructivist beliefs about knowledge.

Criticism does exist over the use of the consensus tenets identified by Lederman (Clough & Olson, 2008; Irzik & Nola, 2011; Matthews, 2012) and alternative constructs such as the Features of Science (FOS) (Matthews, 2012) and Whole Science (Allchin (2011) have been proposed. However as at the time of the study national curricula most clearly resembled the consensus NOS tenets, it is this range of NOS concepts that the researcher set out to examine.

The description of NOS in the New Zealand science curriculum (Ministry of Education, 2007b), which is not as explicit as the outline developed by Lederman, introduces targeted concepts and practices that aim to build students' understanding and familiarity of the NOS as they progress through levels one to seven. In keeping with the objectives of the New Zealand curriculum, it provides generalised statements so that teachers are able to use existing knowledge and available resources (e.g. students' own knowledge and local expertise) to the best of their ability rather than proscribing set activities and progressions. While the expectation of the NZC is not as explicit as the core statements used by Lederman, the NOS strand achievement objectives can be seen to encompass the same concepts.

In the 'understanding about science' strand, concepts such as the tentative nature of science, the theory-laden nature of scientific research and the role of social and cultural influences can all be explored by the teacher and the students. In the 'investigating in science' strand concepts such as the diversity of scientific methods, the role of empirical evidence, the distinctions between terms such as inference and observations, and between laws and theories can all be explored. In this strand the role of creativity and imagination throughout all areas of science can also be examined.

Both the 'communicating in science' and the 'participating and contributing in science' strands are areas where NOS concepts can be explicitly used and explored. Activities such as taking part in informed debates on socio-scientific issues utilize the understanding students develop in the other strands and help identify for students the range of contexts which NOS influences. Within the wide scope of the NOS strands students should therefore be exposed to all the aspects necessary to produce an informed NOS framework which a scientifically literate population needs to negotiate and manage life in a heavily scientific and technologically influenced global society.

This form of a NOS program has the advantage of allowing well informed teachers to pursue current and developing scientific ideas as well as historical examples of scientific development and preventing NOS from becoming what Matthews (2012) warns could become a mantra that is rote learnt by students. This pedagogical design is in line with the American Association for the Advancement of Science (AAAS) Benchmarks for Science Literacy document which emphasized the importance of knowledge of the methods and historical development of science for the advancement of a scientifically literate population (AAAS, 1993). It is also consistent with the National Science Education Standards published by the National Research Council (NRC, 1996) and with their cross cutting concepts included in the Next Generation Science Standards (NRC, 2013).

However despite the Programme for International Student Assessment (PISA) evidence that the top students in New Zealand are among the most scientifically literate in the world (Coll et al., 2010; Telford, 2008) evidence both nationally and internationally indicates that there is a gulf between the NOS rhetoric of national curricula and the realities of classroom practice (Hipkins, Barker, & Bolstad, 2005). Two complementary issues appear to be contributing to this situation, the way we assess and monitor students' NOS development and the persistence of students' intuitive NOS beliefs.

2.3. Assessing NOS

The need to be aware of the influence of students' prior knowledge and their intuitive explanations on learning new material is a well established part of exemplary science education (B. Bell, 2005; Schollum & Osborne, 2001; Solomon, 1986; Tasker & Osborne, 2001). Meaningful assessment to gauge and monitor students' knowledge is recognised as an integral part of the learning process, providing both teacher and student with the opportunity to clarify, reflect and identify paths to further learning and development (F. Baker & Glynn, 1997; Lederman et al., 2002). This means successful transfer and integration of informed NOS concepts requires an accurate understanding of what students already know and believe about NOS (Akerson & Abd-El-Khalick, 2005). Such assessments inform teachers' practice allowing them to plan their instruction appropriately (Hackling, 2004) around the students' existing ideas and making them aware of what the student will attend to (Lehrer & Scharmann, 2006).

NOS assessments have traditionally been based on epistemological models of development and their underlying philosophies (Lederman, Wade, & Bell, 1998). Though good NOS instruction has been shown to facilitate epistemological development (C. L. Smith, Maclin, Houghton, & Hennessey, 2000) the majority of students never reach the advanced stages of epistemological development while at secondary school. National curriculum documents recognise this and instead of trying to teach advanced philosophical techniques, focus on non-controversial but fundamental concepts that enable students to make basic but valid evaluations of scientific knowledge claims. By focussing on simplified declarative statements NOS education shifts away from epistemological development and towards how students internalise and integrate the NOS concepts presented to them. In this way, students can learn to distinguish between scientific claims that are observational versus those that are inferential. By comparison, many traditional NOS assessments are fundamentally inappropriate for high school students as they had been developed with university students and often measured levels of epistemological development and reasoning, rather than knowledge or awareness of NOS concepts (Lederman, Wade, et al., 1998). By focusing on levels of epistemological development many of the current assessment tools are inappropriate for secondary school students and provide teachers with little beneficial information. Rather than providing insight into the students' understanding of science, they present a general view of their epistemology.

To be of benefit for classroom teachers NOS assessments need to probe school students' current knowledge and understanding of core NOS concepts so that teachers can plan and implement effective lessons. Beginning with the Views on Science, Technology and Society (VOSTS) questionnaire (Aikenhead & Ryan, 1992) researchers interested in school students' understanding of science began to develop questionnaires to address this issue. Prior to this work NOS assessment was based on students' agreement or disagreement with expert statements about the nature and limitations of scientific knowledge. It was assumed that the students would correctly interpret the statements only in the way that researchers intended (Lederman, Wade, et al., 1998). Avoiding this assumption VOSTS used interviews and questionnaire trials with grade 11 and 12 Canadian high school students to generate a list of the most common answers to each statement (Aikenhead & Ryan, 1992). The result was a questionnaire where each statement was presented with a list of student-generated responses. Participants were asked to circle the response that was closest to their personal belief. While this format introduced student-generated answers, interviews with participants in later studies found that many students' personal belief were either not represented or were a combination of two or more options so they had not been able to select a response they considered appropriate (Lederman, et al. 2002).

Based on this feedback Lederman and colleagues continued the move towards qualitative focussed assessments with the development of the VNOS open-ended questionnaires. Beginning with VNOS-A Lederman and O'Malley (1990) used semi-structured interviews with high school students to verify their interpretations of the student responses to the open-ended questionnaire. They found significant errors in the inferences they had drawn about the students' beliefs about science and the way students had understood the items in the questionnaire. Abd-El-Khalick et al. (1998) continued this line of research developing the VNOS-B questionnaire with preservice teachers. By interviewing the participants alongside their completed questionnaires and asking the participants to explain their response choice the data lead to the development of the VNOS-C questionnaire. The same study made further modifications following similarly structured interviews with undergrad students, preservice elementary teachers, secondary school science teachers and NOS experts. This then lead to the development of the current VNOS–D questionnaire (Lederman, et al. 2002). VNOS-D presents participants with a series of open-ended questions that a trained researcher interprets.

While these tools and the others based on similar conceptions (Lederman, Wade, et al., 1998; Pomeroy, 1993; Tsai, 1998) have provided enormous insights for educational researchers into the ways school students, university students and teachers understand science, they have been of little practical use to teachers as assessment tools. Questionnaires such as VNOS-D take approximately 45-60 minutes to administer and Lederman et al. (2002) recommend that to ensure correct interpretation of the responses a sufficient number of participants need to be individually interviewed until the researcher attains sufficient expertise in interpreting the responses. While this procedure is suitable for researchers it is impractical for use by teachers who have to operate within the constraints of the classroom and do not have the time or resources to administer or manage such detailed NOS assessments.

Simplified versions of NOS questionnaires have been created. Chen's (2006) Views of Science and Education (VOSE) questionnaire was developed with university students in Taiwan. VOSE uses the core VNOS statements but like the earlier VOSTS questionnaire presents students with a choice of the most common responses. While such questionnaires are more useful for teachers they still have limitations. Like the VNOS and the VOSTS questionnaires many of the statements and response options contain language and terminology that is too complex or ambiguous for secondary school students to answer consistently or accurately. This means that many of the responses students give may be educated guesses rather than internally held beliefs. The range of responses provided can create dilemmas for participants; there may be no options with which they agree, or conversely, they may believe that several options are accurate.

Interviews with Thai preservice teachers who completed a NOS questionnaire also show a further limitation to the current NOS assessment practice. When Buaraphan and Sung-Ong (2009) conducted follow up interviews they found that while the participants' questionnaire responses placed them in the same NOS category, the interviews revealed the participants had diverse beliefs and had used inconsistent reasoning to select the same responses.

This reflects the limited picture that emerges from a unidimensional NOS framework. NOS responses are generally grouped into one of three categories that reflect epistemological development models (Hofer & Pintrich, 1997, Limón, 2006). Responses are naïve if they represent uncritical empiricist reasoning, i.e., new knowledge is absolute and unambiguous, it does not require interpretation. Responses are transitional if they reflect some development towards relativist or evaluativist judgements, i.e., an awareness of multiple interpretations. Responses are informed if they are evaluativist and consistent with expert NOS beliefs, i.e. judgements are reflective of evidence and recognise the limitations of science (Chen, 2006; Lederman, et al., 2002; Tsai, 1998). In research literature this terminology does vary depending on the researcher's beliefs about the implied message associated with the three categories, but the divisions are ubiquitous within NOS and epistemological research. In addition, the NOS tenets present in educational documents represent non-controversial statements intended to help students conduct a basic evaluation of scientific information. Knowledge of these NOS tenets is not evidence of the students having developed an advanced epistemological understanding. Instead responses consistent with expert beliefs indicate that students' are aware of the tenets but give no indication of whether they have integrated the new knowledge into their existing beliefs or if they are using them appropriately.

This distinction between students declarative knowledge and the applied reasoning is highlighted by multidimensional studies in which students are assessed on each NOS concept independently (Deng, Chen, Tsai, & Chai, 2011). In interviews with four male and four female high school students from four classes before and after a biology inquiry unit intervention Sandoval and Morrison (2003) found that the students did not possess coherent epistemological frameworks. Instead students held informed beliefs with regard to some aspects of NOS but naive beliefs about others. Tsai (1999, 2006) also found evidence that educational NOS concepts are context dependent and are not applied consistently as advanced epistemology beliefs would be expected to be. In an eight month case study with Taiwanese grade 10 girls (N=110) Tsai (1999) found that while students adopted the NOS concepts taught in the lessons they were inconsistent with their application in novel contexts. Additionally surveys with Taiwanese 16-18 year old students (N=428) found that they were more comfortable applying NOS concepts to biological science than to physical science (Chin-Chung Tsai, 2006).

Such multidimensional NOS studies indicate that rather than basing NOS analysis on a unidimensional epistemological model, a more useful interpretation of NOS is to treat each NOS concept as a distinct declarative knowledge statement and examine each NOS tenet separately. Naïve and informed beliefs still represent the two poles and a continuum of increasing understanding (Khishfe, 2008) is assumed to lie between them. This approach assumes each participant personal experience and prior knowledge will affect their beliefs about each NOS dimension in a different way. This finer grained models of NOS understanding is better suited to helping identify students' beliefs regarding NOS and can help identify the influences that shape and mould their beliefs. Teachers need this information if they are to be adequately informed about the prior-knowledge that shapes students' beliefs and so plan instruction accordingly (Hackling, 2004).

2.4. NOS Influences

Studies have continued to show that there is widespread weakness in the understanding of NOS by both students and teachers (Afonso & Gilbert, 2010; Lederman, 2007). Despite the increasing emphasis on NOS education, most science classrooms still focus on the accumulation of facts for later recall (Huang, Tsai, &

Chang, 2005). Science continues to be presented as the unproblematic pursuit of absolute knowledge via a ‘cookbook’ scientific method that produces absolute results (J. Osborne, et al., 2003) based solely on objective reasoning (R. Baker, 1997; Carr, et al., 1997). This traditional view of science is often reinforced in the classroom by textbooks (Irez, 2009), ‘cooked’ classroom experiments (Laws, 1997), idealised teacher demonstrations and classroom environments that focus on exam success (Roberts & Gott, 2004). The contribution of teachers in creating this classroom environment is well established in the literature and a number of important issues have been identified.

Many teachers see NOS as being of limited use, containing ephemeral ideas that do not integrate with their traditional science lesson objectives (Abd-El-Khalick, et al., 1998; Hipkins, et al., 2005) and which occupy valuable time in an already overloaded curriculum (Clough, 2006). As a result teachers treat NOS sections of the curriculum as either a set of ‘add-on’ pages to be turned over (Clough, 2006; Loveless & Barker, 2000) or regard its content as a checklist of procedures and tenets that students need to learn by rote (Hume & Coll, 2008; McComas et al., 1998). Research has identified four broad factors that result in teachers presenting inappropriate images of NOS to their students;

- teachers own naïve epistemology beliefs about knowledge (Abd-El-Khalick & Akerson, 2004; Akerson et al., 2008; Entwistle & Smith, 2002; Kang, 2008)
- teachers lack of or ill-informed knowledge of appropriate NOS concepts (McComas, et al., 1998);
- classroom constraints such as a lack of NOS resources (Loveless & Barker, 2000) and the pressure of exam success (Akerson, Buzzelli, & Donnelly, 2010; Roberts & Gott, 2004) that limit the time teachers have to deal with NOS concepts;
- teachers’ classroom practices that reinforce non-informed NOS beliefs (R. L. Bell, Lederman, & Abd-El-Khalick, 1998; Khishfe & Abd-El-Khalick, 2002; Russ, Scherr, Hammer, & Mikeska, 2008; Ryder & Leach, 2008).

To address these issues explicit NOS training has been developed to enhance pre-service teacher understanding of NOS concepts and to develop appropriate classroom practice (Abd-El-Khalick & Akerson, 2009; Akerson, Abd-El-Khalick, & Lederman, 2000; H. Bartholomew, Osborne, & Ratcliffe, 2004; Deniz, 2011; Khishfe & Lederman, 2006; M.U. Smith & Scharmann, 2008). Additionally NOS activities and resources have been developed to facilitate this teaching and to help develop an environment consistent with the NOS concepts such as the Royal Society of Chemistry's *Nature of science* (Warren, 2001) and other research based studies (Khishfe, 2008; Kim & Irving, 2010; Peters & Kitsantas, 2010; Scharmann, Smith, James, & Jensen, 2005).

Despite the contributions of these factors it does not appear to be enough to ensure that NOS tenets are learnt and actively applied by students. In a project involving 7th grade gifted students from Taiwan (N=19) Liu and Lederman (2002) conducted an explicit NOS intervention program. Despite the expert NOS knowledge possessed by the presenters and the entirely NOS focussed program they found no significant change in the students' NOS beliefs. This is consistent with the realization that students do not come into the classroom as blank slates but arrive with a vast array of implicitly developed concepts and theories about the natural world and the way science works formed from their personal experiences (Afonso & Gilbert, 2010; Freyberg & Osborne, 2001; R. Osborne, 2001). The influence of prior knowledge on the way students understand science concepts was a central part of the findings from the Learning in Science Project (LiSP) conducted by Roger Osborne and Peter Freyberg in New Zealand (R. Osborne & Freyberg, 2001). They found that students interpreted new information through their own experiences and understood scientific terms and concepts in terms of their everyday usages. These intuitive beliefs that students develop about science are powerful and can be resistant to change, persevering even in the face of informed explicit NOS instruction (Afonso & Gilbert, 2010; Clough, 2006; Driver, et al., 1996).

The perseverance of personal beliefs and the reluctance to change worldviews is consistent with constructivist theories of learning. From this perspective, any new information will be constructed in a way that makes sense to the individual (Loughran, 2010). Information may be adjusted so it can be assimilated into current understanding or it may elicit cognitive change, in which case it is accommodated by the alteration of current understanding (Posner, Strike, Hewson, & Gertzog, 1982). New learning is dependent on current understanding and so will be integrated into what students already understand and believe about a subject or concept. This means students will be constructing and integrating new ideas about NOS in light of their prior knowledge and experience. The assumptions and intuitive beliefs that they have already formed will significantly influence the value and validity students give to the new information and affect the way that they will attend to the new information and integrate it.

Teachers need to understand and recognise the ideas about NOS their students already possess if they are to engage in effective and lasting NOS instruction (Akerson & Abd-El-Khalick, 2005; Hackling, 2004). Teachers need to be aware that external factors such as family, culture and peers, all influence students' beliefs about scientific knowledge (Costa, 1995) and the way that these factors shape students' intuitive NOS beliefs.

A number of studies have already highlighted the effect family and parental factors may have on students' beliefs. In a nationwide representative study of grade 10 students (*N*= 2020) and science teachers (*N*=362) in Turkey a number of factors were found to correlate to NOS beliefs. Using a modified version of the VOSTS questionnaire Dogan and Abd-El-Khalick (2008) identified significant correlations between levels of parental education, socio-economic status (SES), and westernisation with informed NOS beliefs. This is consistent with the findings of Robottom & Norhaidah (2008) whose comparison report found that westernised year 10 Muslim students in Australia (*n*=99) held more informed views about NOS than form 4 Muslim students in Malaysia (*n*= 549). However, the difference in data collection techniques between the two studies, and the difference in school systems would also have had an effect on the divergence of the two studies. Additionally neither study explored parental aspirations that Bynner, in the early 70's, identified in a statistical analysis of 3000 UK students and their parents as the most potent factor in students' academic success (Solomon, 2003). What these studies show is the importance of students' personal background in establishing the cognitive beliefs they bring to the classroom.

Personal goals and the perceived utility value of knowledge also play a significant role in how students integrate new ideas (Nieswandt & Shanahan, 2008). In-depth interviews with the Islamic students from Australia indicated that while many students were culturally uncomfortable with evolution, they had compartmentalised the information, recognising it as necessary to retain for achieving their future goals but not incorporating it into their core beliefs (Robottom & Norhaidah, 2008). This willingness to accept information for its utility value is not just seen in students engaging in cultural border crossings but in those engaged in crossing between home and school science (Aikenhead & Jegede, 1999). Many students "recognize the value of school science in their goals of attending college but do not see school science as intrinsically meaningful" (Costa, 1995). These sentiments are echoed by 16 year old students in the UK (*N*=144) who took part in focus group discussions about the role and purpose of science education (J. Osborne & Collins, 2001). These students consistently stated that they struggled to identify the real-life application of what they learnt in science, but recognised science was an important requirement for their future goals. Similarly grade 11 boys in Canada (*N*=10) who were followed as part of a classroom case study identified getting the credits they needed as a major motivation for their performance in their science course (Nieswandt & Shanahan, 2008).

Students' focus on the utility value of knowledge highlights the influence formal examinations, both nationally and internationally, have on the way students integrate NOS. As most examinations are dominated by the reproduction of knowledge, examinations shape classroom environments into places where the traditional image of a fact driven science is dominant (Entwistle & Smith, 2002). These environments favour surface learning strategies which can encourage students to develop a realist or absolutist view of science rather than the more appropriate constructivist and evaluativist views (Tsai, 1998). Such classrooms often cover NOS concepts as a set of tenets or procedures that students learn by rote (Clough, 2007; Hume & Coll, 2008) or simply ignore NOS concepts in favour of core examinable content.

Studies into the influences of student beliefs show that these factors, along with such aspects as religion, media, personal experience and personal goals, all play some role in creating student beliefs about science that can be at odds with what the teacher expects (Entwistle & Smith, 2002). These personal biographies not only shape students' prior knowledge and intuitive beliefs but also affect the way they respond to and integrate new knowledge (Robottom & Norhaidah, 2008). The implicit messages students receive about science from the classroom also determine whether informed NOS concepts are rejected, compartmentalised or integrated (Abd-El-Khalick & Akerson, 2004; Chinn & Malhotra, 2002; Clough, 2006). While research has identified ways to improve teacher understanding and delivery of NOS (Abd-El-Khalick, 2005; Akerson, Cullen, & Hanson, 2009; Lederman, 1999; Morrison, Raab, & Ingram, 2009) research into how students' prior knowledge and intuitive beliefs influence their NOS understanding is missing. In order for teachers to successfully apply NOS instruction in their classes they require both practical accurate tools to assess students' NOS beliefs, and detailed information about the intuitive beliefs that exist and influence students' understanding of NOS (Clough, 2006; Cosgrove & Osborne, 2001; McComas et al., 1998).

Previous studies into secondary students' NOS beliefs detected many of the misconceptions that NOS based curricula now aim to overcome. Students have been found to hold hierarchical beliefs about law and theory and to associating theory with hypothesis, and law with proven facts or legal laws (Griffiths & Barry, 1991; Meyling, 1997). In addition students with naïve knowledge beliefs are less likely to successfully integrate empirical evidence from laboratory work with theory (Havdala & Ashkenazi, 2007).

While studies routinely identify student misconceptions about NOS, the prominence of these naïve NOS beliefs amongst students has been difficult to ascertain. A summary of research by Meichtry (1993) regarding students' conceptions of NOS revealed inconsistent results amongst the studies examined. A critical review of studies into students' views of NOS by Deng et al., (2011) also reported inconsistencies. With inconsistent studies into changes in students' NOS beliefs the researcher began to question if the existing NOS taxonomy was detailed enough to detect the range of beliefs students possessed. Could participants be transitioning between the traditional NOS categories and so produce inconsistent responses?

Therefore, in 2010 and 2011 I explored students' NOS beliefs by using a mixed methods approach to identify and purposefully sample year 11 students. As the initial hypothesis, I predicted that students with different questionnaire scores would describe distinct NOS beliefs. This could then be used to create finer-grade NOS taxonomy classification that could help teachers' better target NOS interventions with specific categories of students. In the next chapter, the specific research questions and methodology used to explore students' NOS beliefs are described.

CHAPTER 3 - RESEARCH DESIGN AND METHODOLOGY

3.1. Overview of the Study

This study set out to investigate what New Zealand year 11 students' understand about the nature of science by the end of their compulsory science education. While NOS research has often taken the historical unidimensional approach, treating NOS as a single entity and categorizing participants as naive or informed about NOS, this project took a multidimensional approach (Deng et al., 2011) in order to study how the anticipated distinct beliefs about different NOS tenets affected students' understanding of NOS. To gain a rich, student derived description of what these beliefs were and what influenced them the researcher used a NOS questionnaire and factor analysis to select students who appeared to represent distinct response clusters for in-depth interviews. This method allowed the researcher to probe the ways in which different NOS concepts interacted in forming the students' NOS beliefs and how the students' personal experience and expectations affected these beliefs.

3.2. Research Questions

The primary purpose of this study is to explore year 11 students' understanding of NOS as they completed the last year of compulsory science education. As such, this study sought to address the following research questions:

- What NOS concepts do New Zealand secondary students hold by their final year of compulsory science education?
- How do these concepts compare to core informed educational NOS concepts?
- What factors do students identify as influencing their understanding of NOS concepts?
- How do these influences interact to form the students' belief about NOS?

3.3. Theoretical Frameworks

Theoretical (or conceptual) frameworks act to provide the building blocks that social science researchers use to vigorously and coherently examine socially derived phenomena (Anfara & Mertz, 2006b; Evans, Coon, & Ume, 2011). These frameworks provide useful benchmarks and boundaries that help researchers define and examine the issues they set out to investigate. These social science theories are distinct from natural science theories in that multiple theoretical orientations can co-exist, allowing the researcher or researchers to examine the empirical data collected of the phenomena from multiple perspectives (Anfara & Mertz, 2006b). The theories used and adhered to by researchers define the ontology, epistemology, methodology and ideological perspectives of their work and are important guides for both the researcher and their audience to be aware of (Anfara & Mertz, 2006b). The theoretical framework acts to focuses the study, shaping what insights are revealed and concealed by the researcher's choices and assumptions (Anfara & Mertz, 2006a).

While it is tempting to identify one theoretical framework as being the lens through which a study is conducted, this is rarely an accurate description of the underlying constructs behind a study. While a particular phenomenon may have been identified using one theoretical perspective, the nature of the question raised may require one or more alternative theories to help guide the design, implementation and interpretation of the study (Anfara & Mertz, 2006a). In the case of this research, three theoretical frameworks interacted to define and guide the design and execution of the study (see Figure 3.1).

The first theoretical framework that influences this study is the educational NOS frameworks suggested by Lederman and other researchers (see section 2.2). While educators like Matthews (1993) have argued that educational NOS objectives are not academically rigorous they do provide a necessary guide as to what key concepts and ideas are required for students to develop a rudimentary functional framework for understanding the way science works. This simplified philosophy of science helps identify those innate and acquired ideas and beliefs about science that contribute to naïve beliefs about NOS and provide guidance as to what should be considered informed NOS beliefs.

While the specifics of this framework are defined in the literature review section, as a theoretical lens, NOS theory defines what information was being studied and what should be considered appropriate and inappropriate beliefs. The two extreme positions against which students were assessed were the naïve realist position that envisions science as an unambiguous absolutist endeavour (referred to as naive for simplicity in this study) and the informed evaluativist position that recognises science as a robust but tentative modelling of reality (referred to as informed for simplicity in this study) (Deng et al., 2011; Hofer & Pintrich, 1997). The researcher's own framework for assessing NOS was also shaped by the writings of scientists and authors such as Cohen and Stewart (1995; Stewart & Cohen,1997), Dawkings (2009), and Hawking and Mlodinow (2010) who all describe scientific practices and processes that are consistent with the educational NOS literature. These authors identify the successfulness of science as undeniable but also emphasize that in the absence of any absolute check on reality, the answers proposed by science must be recognized as a form of model-dependent realism, what Cohen and Stewart (1995; Stewart and Cohen,1997) describe as "true for a given value of true". It is within this framework of ideas about what NOS encompasses that the study is based.

The second theoretical framework influencing this work is the constructivist learning theory which has been dominant in both New Zealand and international science curricula (Carr et al., 1997; Matthews, 1995). This particular theory focuses on how individuals, either through social (Vygotsky) or individual (Piaget) actions develop and refine their viable knowledge constructs and develop their beliefs (Magoon, 1977; Von Glasersfeld, 1987). While varied forms of constructivism exist, this study is focussed on the role of educational constructivism (Matthews, 1993; L. Smith, 1999) and specifically how students attain and develop their beliefs about the NOS (Campbell, 1998). The underlying assumption of the study is that students' knowledge of NOS is not learnt via direct transmission as an exact copy but through integration with what the student has already experienced and understood about the NOS and the workings of science (L. Smith, 1999; Von Glasersfeld, 1987). While the *NZC* (Ministry of Education, 2007) is now influenced by socio-cultural theory, the historical legacy of its earlier constructivist influenced curricula remains and guides much of the teaching and learning practice seen in classrooms (B. Bell, 2005; Carr et al., 1997).

The constructivist framework is a key component in assessing what is being learnt and understood and how it is being shaped by the students' experiences and is the commonly recommended pedagogical approach found in science education literature (Deng et al., 2011). This theoretical lens provides the analytical framework used to interpret the data generated from the students. The fundamental assumption of the researcher in this project is that students were using their experience of science, both in class and outside of it, to construct their understanding of NOS and that this would be reflected in the questionnaire response profiles and the interview data.

The final theoretical framework that guided this study is pragmatism. As with the other frameworks pragmatism has a number of branches and, this study focussed on the instrumentalist pragmatism popularised by the American educator and philosopher John Dewey. This form of educational pragmatism identifies that the key requirement of educational research is to identify what is needed to bring about the desired results (Feilzer, 2010). In this particular case by trying to understand what NOS concepts held by student and how they are formed this research intended to provide evidence and guidance to help teachers identify ways to develop sound NOS beliefs amongst students. Pragmatism is utilized in two ways through the project. First, it set out to look for direct evidence of what students understood about NOS and for ways in which teachers could enhance that understanding.

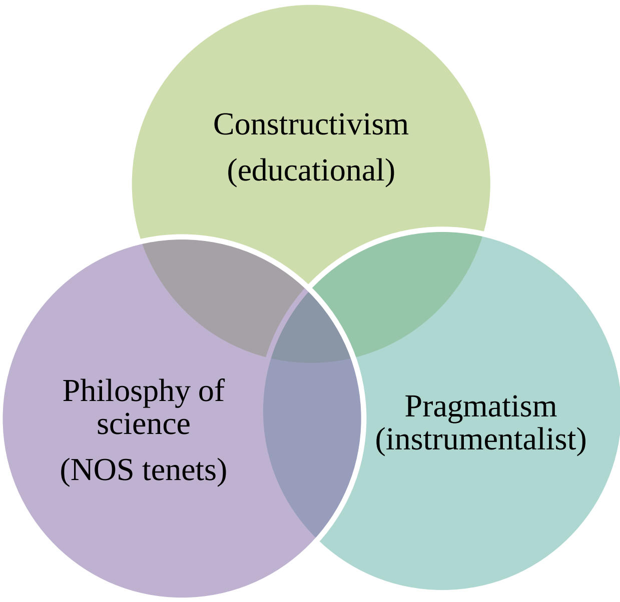

Figure 3.1. The overlapping theoretical frameworks guiding this study

Second, it helped set out the practical parameters for the study. The instrumentalist lens helped the researcher focus on what aspects of the study to develop and how the resources, opportunities and emerging data could best be utilised through a sequential mixed method study (Creswell & Plano Clark, 2007). By applying a pragmatic lens that kept the researcher focussed on the research questions and the developments most relevant to investigating the students' NOS beliefs, the researcher was able to navigate through the overlapping aspects associated with this study such as philosophy of science, epistemology, ontology and research methodologies. While all of these factors were important aspects that the researcher needed to investigate and make decisions on, the use of an instrumentalist pragmatic lens (Feilzer, 2010) helped prevent the study from diverting too far from the focus of the research questions initially set out in the study.

3.4. Methodology Overview

As argued in the previous section, as students' construction of knowledge plays a significant role in education, exploring students' understanding of NOS necessitated an investigation into the construction of the knowledge and beliefs they held about science. The most informative and insightful method for investigating this was through the students' own words. Applying a pragmatic paradigm (Feilzer, 2010) the researcher decided to use a sequential explanatory mixed methods study set out over three stages (see Figure 3.2);

- an initial quantitative questionnaire to purposefully select typical case students (Creswell & Plano Clark, 2007; Johnson & Christensen, 2008) from a pool of test subjects (*N*=502) to interview about their NOS beliefs (Tsai, 1998),
- a qualitative data collection stage where the selected students (*n*=22) were interviewed about NOS tenets,
- a thematic analysis stage where the data generated by the two previous stages were combined to identify major themes and to establish what level of symmetry existed within the stages of the study (Usher, 2009).

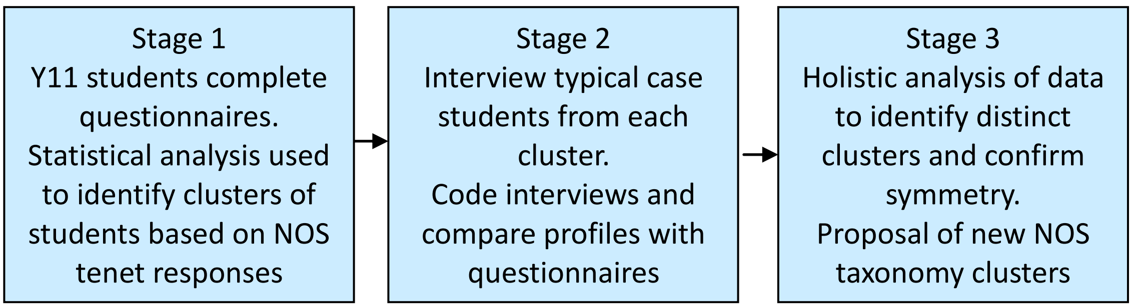

Figure 3.2. Diagrammatic overview of the research proposal

3.4.1. Initial study framework

By selecting a sequential mixed method study the researcher set out with an initial research design and plan that was modified at each stage by the emerging data. This prevented the researcher from being locked into a research design that was unable to analyze the emerging data, but at the same time created a framework to guide the successive stages and maintain focus on answering the primary research questions and the new emerging research questions that were generated by the study itself. The following gives an overview of the study's methodology that is detailed through sections 4 to 12.

The study set out to explore students' understanding of NOS. Specifically it set out to see if multidimensional NOS tenets responses were linked to particular beliefs or experiences of students. Based on the research literature (see section 2.3) the researcher anticipated that NOS tenets would be responded to in different ways by different clusters of students, i.e., some students would be either informed or naive about all the tenets while other students would show a mixture of responses to different tenets (see Table 3.1). The interviews would explore the students' understanding of NOS and identify the specific beliefs and experiences that generated the different clusters of beliefs. This information would then be used to inform teaching and assessment practices to help raise the overall NOS knowledge and understanding of students.

Table 3.1

Possible student responses to NOS tenets

Tenet	Tentative	Law & Theory	Social	Scientific method	Empirical
Student 'A' responses	Informed	Informed	Naive	Naive	Informed
Student 'B' responses	Naive	Naive	Naive	Naive	Informed
Student 'C' responses	Informed	Naive	Naive	Naive	Informed

3.4.2. Participants selection

Year 11 students were selected for this study as this group represents the last year of formal science education for many New Zealand school students. Many will likely have formed their lasting perceptions of science by this stage (Hume, 2008). Of the co-educational secondary schools from the New Zealand region approached, four agreed to take part in the study. A total of 502 co-educational year 11 students from these schools agreed to take part in the study and fully completed the survey. Based on the students' questionnaire responses 60 students were invited to take part in the interviews, of which 22 agreed and gained parental permission to take part. These students represented a mix of questionnaire response scores.

3.4.3. Ethics protocol

Ethical approval for the study was granted by the Victoria University of Wellington Faculty of Education Ethics Committee under application no. 17855. Schools were approached to take part anonymously in the study. Demographic details needed to allow for the comparison or replication of this study was limited to that information that would ensure both schools and participants remained anonymous.

Once permission had been granted by the head of the school, the researcher met with the students to brief them on the purpose of the study and to review their rights as participants. In accordance with the Education Ethics Committee recommendation, passive parental consent was sought for use with the questionnaire phase of the study as the data collected was deemed to be low risk (see Appendix F). This form was sent home with students so that parents who did not wish their child to take part in the study could withdraw consent.

Prior to the questionnaires being administered, the students were reminded by the researcher that participation was voluntary and that students could leave any item they wished unanswered. The students were informed that they could withdraw consent at any stage after the data had been collected. The researcher read through the student consent form with the participants (see Appendix E) and answered any questions the students had about the study prior to the students signing the form. Students were also asked to indicate on the form if they would consent to participating in the interview phase of the study but were assured that this was non-binding.

Once the questionnaire data had been analysed, students who had indicated they would be willing to be included in the interviews were approached through their science teachers. If they were still willing to participate a parental consent form (see Appendix G) was sent home with them. On the days of the interviews, only those students who had returned the forms and still consented to be interviewed met with the researcher.

Prior to the interview the purpose of the study was again explained to the student and their rights as a participant were reviewed and any questions they had answered. During the interviews students were able to skip over or return to any questions or comments they wished to clarify. After the interview was complete they were able to review the interview and alter or clarify any answers. Students were also given the opportunity to withdraw consent after the interviews

3.4.4. NOS questionnaire and factor analysis

While an initial search was made to find an existing NOS questionnaire for the study the researcher ultimately created a study specific questionnaire (see section 4 for development details). This questionnaire utilised modified existing NOS items and newly generated items based on NOS literature (e.g. McComas & Olsen, 1998, Osborne et al, 2003 and Lederman & Lederman, 2004b) to probe five NOS tenets. Not all the tenets identified by Lederman were used in this study. Those tenets that were identified by the researcher as requiring significant contextual explanations and guidance were excluded. These tenets, while in part probed in the interviews, were identified as tenets that would be better probed by a methodology that could examine students' enacted application of science (Sandoval, 2005). The remaining tenets were then examined and where appropriate were combined to form five tenets that could probe students declarative knowledge about NOS. These revised tenets are described below along with a contextual example to help illustrate the tenet for the benefit of the reader. The final items used to probe each tenet were deliberately left without specific scientific knowledge (see section 9.2 for the final listing of items by tenet used in the study proper).

Tenet 1 - Scientific knowledge is durable but tentative;

Scientific knowledge represents human constructed interpretations and explanations of phenomena about the natural world. It is never absolute or certain about its claims as new interpretations, new ideas, new evidence, new discoveries, and improved technology can all change how scientists describe and explain the natural world.

Example: *early genetic models worked on a simple 'one gene – one protein' basis to describe the role of DNA. This has been replaced by a proteomics model in which numerous layers of interactions mean one gene can generate multiple proteins.*

Seven items probed this theme; three were written to represent an informed position and four a naive position.

Tenet 2 - Scientific laws and theories not hierarchical levels of scientific knowledge;

Scientific laws are descriptive statements about the relationships between observable phenomena. Scientific theories are inferred explanations about phenomena. Theories do not mature into laws; rather, the two represent distinct types of scientific knowledge

Example: *Newton's laws of gravity mathematically described the way gravity worked but could not explain it; Einstein's theories of relativity give an explanation of what gravity is.*

Eight items probed this theme; four were written to represent an informed position and four a naive position.

Tenet 3 – Interpretation of scientific data is affected by social and personal beliefs;

Scientists use creativity and imagination to form possible explanations and interpretations. This will be affected by society and culture through such things as social values, political agendas, socioeconomic factors and religious beliefs. It will also be affected by pre-existing scientific explanations and viewpoints.

Example: *Naturalists in the 18th century interpreted biological adaptations as evidence of an intelligent designer whereas modern biologists interpret the same adaptations as evidence of evolution by natural selection.*

Eight items probed this theme; four were written to represent an informed position and four a naive position.

Tenet 4 – There is no single scientific method;

The scientific method is not a universal method used by all scientists, instead it refers to the diverse but related group of inquiry skills that help identify valid questions, determine the appropriate strategies to investigate the question, and inform the researcher on how to examine and interpret data about the phenomena

Example: *Cosmologists cannot carry out true controlled experiments but do use the same set of general inquiry skills to investigate and develop knowledge about the universe.*

Six items probed this theme; three were written to represent an informed position and three a naive position.

Tenet 5 – Science is based on empirical evidence

All scientific knowledge is, at least partially, based on observations about the natural world. Explanations must be checked against what actually occurs in nature.

Example: *The demise of phlogiston theory by the series of quantitative experiments that showed substances gained mass when burnt rather than lost mass.*

Six items probed this theme; three were written to represent an informed position and three a naive position.

A minimum of six items were developed for each tenet. For three tenets the researcher had additional items and decided to retain the items so later empirical data could distinguish which items were most informative. The items used in the final version of the questionnaire were written to reflect the established NOS taxonomy of naive and informed beliefs. Half of the items for each tenet were written to reflect naive beliefs and half to reflect informed beliefs. This was intended to act as a logical check and a validity test as students who responded strongly to an informed item should respond in a mirror way to naive statement (Carifio & Perla, 2007). The questionnaire utilised a nine-point Likert response format response anchored by strongly agree and strongly disagree positions spaced either side of the neutral neither agree nor disagree position. The odd numbered points between the two anchors were labelled while the even points were left unlabelled so students had a greater degree of response options to each item and could select graduations between the labelled points.

To allow the data to be analysed the response format was then coded into a numerical scale. As the researcher had no empirical data on which to base a judgement about the magnitude of the units between the two anchor points of the response format (Carifio & Perla, 2007), a linear scale was used so that each Likert response was converted to a number between 1 and 9. For each item the most naive response was scored as a 1 and the most informed response scored as a 9 with response format positions between these two anchor points scored along a linear scale (e.g., the neither agree nor disagree response was scored as a five).

This decision reflected the intention of the questionnaire to act as a screening device to help select students for interviews about NOS tenet beliefs rather than an attempt to validate another new NOS assessment tool. The mechanical limitations of such a choice on the calculation of correlation coefficients was expected to be minimal compared to differences in responses to each tenet and was not expected to hinder the selection of students based on the clusters formed by tenet responses.

Once the statements were developed to a satisfactory level and had been given to local NOS experts for face validity confirmation, the questionnaire was administered to year 11 students (N=502) and the responses coded into an ordinal scale. Inter-item reliabilities of each tenet were tested and a confirmatory factor analysis (CFA) was conducted to measure the goodness of fit of the theoretically derived five NOS tenet model (see sections 7 and 8).

This analysis revealed poor goodness of fit data despite expert verification of the tenet items during the development phase. While the statistical software identified specific items that did not fit the model, the researcher could only identify substantive reasons to justify the exclusion of some of the items. Rather than removing all the items identified to enhance the fit of the theoretical model, the researcher explored other possible factor solutions based on advice from an expert in statistical analysis (Hodis, 2011, May).

The data was randomly split into two subsamples (*n=251*) and exploratory factor analysis (EFA) was conducted to identify alternative factor solutions. Each statistically generated model was tested for goodness of fit by CFA with the second half of the data set to identify if a better fitting model with substantive underpinnings could explain the distribution and correlations of the data (see section 10). From this analysis the researcher identified a four-factor model as being the most parsimonious fit to the data. The factor loadings from this model were used to identify students to interview as the focus of the interviews shifted to explore why students responded to the items so differently than anticipated.

3.4.5. Interviews and coding

As the qualitative data indicated that different constructs were underlying the students' responses to the questionnaire the second stage of the study was modified to reflect this. Rather than selecting students based on the theoretical construct the researcher selected students based on the four-factor model. Following the advice of a statistical expert, students were scored based on the mean and standard deviation of the responses to each of the items (Hodis, 2011, May). The items scores were then summed based on the four-factor model identified by the factor analysis and students were separated into three groups based on if they were above, below or within one standard deviation of the summed score mean (see section 11).

Twenty two students subsequently agreed to take part in the interviews and returned signed parental consent forms. Three male and three female students from the group scored greater than one deviation of the mean, three male and eight female students scored within one standard deviation of the mean, and two male and three female students scored lower than one standard deviation of the mean. Code numbers were used prior to the interviews by a research assistant to ensure the researcher did not know which category each student belonged to. This was done to help reduce interviewer bias.

The interviews took place in space provided by each school during regular classroom hours. The semi-structured interviews were recorded and transcribed for coding analysis by the researcher. Pen and paper was also provided to the student during the interview to allow them to annotate any ideas as student's responses often reflect the limitations of their language rather than of their understanding (Fleer & Robbins, 2003).

The interviews focused on the following open-ended questions;

What is science?

How is science different to other subjects?

How does school science compare to 'real' science?

Do beliefs affect scientists?

What does law and theory mean?

What is the scientific method?

What has affected your beliefs about science?

For each question asked, subsequent specific questions were generated in situ, to explore the reasoning and meaning of the students' answers (Freyberg & Osborne, 2001). This allowed the researcher to respond more dynamically to the nature of each individual's response and explore any unexpected data that surfaced (Feilzer, 2010; Fleer & Robbins, 2003; Usher, 2009). To minimize the effects of interviewer bias and distortion the interview checklist and procedures developed by Bell, Osborne and Tasker (2001) were used.

The coding process consisted of three sequential stages. In the first the researcher made individual profile notes of each interview noting potential themes and categories on the transcript and comparing the coding with post interview notes made at the time of the interviews (Seidman, 2006). In the second stage the researcher used NVivo 9 software to help compare the coding categories of all the interviews. Nodes for each interview question were used to collate similar responses and to identify the varied beliefs and ideas expressed by the students. At this stage, a second researcher took part in the coding to enhance coding validity (Merriam, 2009). A co-coded and individually coded transcript were compared and discrepancies were discussed and changes to the coding process were made

In the final stage the coding nodes were reduced to the minimum number of categories needed to accommodate all the responses while still ensuring the categories were an accurate representation of the students' beliefs (Seidman, 2006). For each interview node, the student's text was reviewed to identify categories that could be merged or needed to be divided. Categories with only one student were examined to see if it could be merged with another. The researcher then reviewed each student's transcript for any additional comments or contextual features that were relevant to the category to which a student response was coded.

The researcher then tabulated the data for each interview question, sorting the students by their questionnaire sampling groups (i.e., high, medium and low scores) and marking on the tables what response category they belonged to. From this, unified descriptions of each category were created that captured the responses of the students in that group. As a final validity review a second researcher with science expertise reviewed the work to provide peer reviewed feedback about the appropriateness of the final coding categories (Merriam, 2009).

3.4.6. Mixed analysis

Mixed methods research can balance the limitations inherent in qualitative and quantitative methodologies and in addition generate enriched informative data (Bergman, 2010; Harris & Brown, 2010; Onwuegbuzie & Combs, 2011). However, to be useful the initial data sources must not only be analysed through acceptable methods to find meaningful inferences, but they must then be integrated in a way that enhances each data set and reveals additional understanding (Creswell & Tashakkori, 2007; Harris & Brown, 2010).

While mixing is the most problematic stage of the research (Creswell & Plano Clark, 2007), it can provide mutually supportive and informative detail (Bergman, 2010; Usher, 2009) if the researcher's interpretations are consistent with the theoretical underpinnings of the study and are empirically supported (Yardley & Bishop, 2008). In addition it should not be assumed that corroborating evidence will be found (Yardley & Bishop, 2008). The researcher must ensure that the initial data analysis stages have minimised threats to validity by being designed and executed appropriately (Creswell & Plano Clark, 2007). Even then additional factors such as lack of participant variability, greater qualitative sensitivity to context and construct over-complexity may make the data incompatible (Harris & Brown, 2010). Finally the researcher needs to develop sufficient expertise with each method, or have access to that expertise, if the study is produce enriched data (Yardley & Bishop, 2008).

The way in which the data sets are merged, depends on the way in which the study is conducted (Creswell & Plano Clark, 2007). As a sequential explanatory design the study used the quantitative data from the first phase to guide the data collection of the second phase (Creswell & Plano Clark, 2007). The emergence from the questionnaire of unexpected constructs and the identification of non-loading items contributed to the selection of interview participants and altered the focus of the interview questions. These interviews themselves revealed additional insights and appeared to support the quantitative results that informed NOS beliefs were not guiding the students' responses.

During the mixed analysis the researcher looked for complimentary evidence from the two data sets that could help confirm and explain that alternative constructs were guiding the students' understanding of science. Taking the coded data from each interview section, the researcher examined it alongside the item response data for the interview groups (see Chapter 12) and from the qualitative data sets. The researcher first focused on the non-loading items (see section 12.1) and then examined the students' descriptions of science to see how they could be matched to the constructs that emerged from the questionnaire data (see section 12.2). The researcher identified points of symmetry between the two data sets and was able to identify a simplified model of science from the students' interview descriptions that indicated all the students' questionnaire responses were derived from naïve realist beliefs.

Through the next four chapters the methodology of the pilot study phases is broken down to allow the reader to easily reference each of the stages. Chapter four outlines the rationale and considerations taken by the researcher in deciding to develop a study specific NOS questionnaire and identifies the resources used to develop the items and the structure of the response tool. Chapter five describes the methodology used for the initial pilot study while chapter six examines the statistical results of the pilot study and the insights gained from the focus group. This chapter concludes with an item by item breakdown of changes to the original questionnaire and the resulting modifications brought about by the pilot study (see section 6.3.8). Chapters seven and eight provide the same overview for the second pilot study which tested the revised questionnaire. It also includes the recommendations of national NOS experts who provided feedback on the items and identifies the additional emergent questions that were raised from the pilot studies. The study proper then begins in chapter nine.

CHAPTER 4 – QUESTIONNAIRE DEVELOPMENT

Introduction

To find a tool appropriate for the selective sampling intended for this study, four key questions, outlined by Fallowfield (1995), were applied by the researcher:

i) Whom is the questionnaire for?
ii) Does an established questionnaire exist?
iii) Are items brief, relevant and unambiguous?
iv) What response format will be used?

Applying these considerations, the initial question of who the questionnaire was intended for needed to remain of critical importance throughout the development stages. Year 11 students in New Zealand range usually between 14 to 16 years of age and have experienced at least 10 years of science in the New Zealand curriculum. They can have diverse linguistic backgrounds that mean English may not be their primary language spoken at home.

While they all have exposure to science in accordance with the New Zealand curriculum, the depth to which this knowledge may have developed varies. Any questionnaire would have to include language structured in a way that was familiar and comprehensible to New Zealand students and that would include science references that were within their range of scientific exposure. In addition, to meet the purpose of the screening stage of the study the questionnaire needed to be able to be administered and completed in the limited time available. Each statement was required to be brief and contain a single clause while using language and context that was at an appropriate level.

4.1. Questionnaire review

Operating within these parameters, the researcher reviewed existing NOS questionnaires to see if one would be suitable for use with the secondary school student population intended for the study. The first tool examined was the V-NOS questionnaire developed by Lederman and colleagues (Lederman et al., 2002), arguably the most commonly used NOS assessment tool. While the latest version of the questionnaire is supported by significant research, its open-ended response structure requires a considerable amount of time for participants to complete and specific trained skill by a researcher to interpret appropriately. As an intended screening device, V-NOS did not meet the desired parameters for this study as the participants were only available for a limited time and the primary purpose of the questionnaire was to help identify students to take part in the later interviews.

Chen's VOSE questionnaire (Chen, 2006) has the benefit of examining NOS using a Likert scale, allowing for faster data gathering. The researcher carried out an initial trial using this questionnaire with a postgraduate cohort group and a research scientist. The feedback from these initial trials indicated that some of the existing vocabulary was confusing and the participants identified some of the statements as ambiguous in nature. As secondary school students were unlikely to possess the academic ability or interpretation skills needed to handle such ambiguity (Byrne & Watkins, 2003; Watkins & Cheung, 1995) the VOSE questionnaire was subsequently excluded as a viable tool for use in its existing form.

In examining other NOS questionnaires referenced in NOS literature no single questionnaire examined met the requirements for this study of i) being usable with secondary students from a wide range of academic backgrounds, ii) being able to be completed quickly and easily by students and iii) reflecting the specific NOS concepts that were of interest to the researcher.

As a result, the researcher began to develop an amalgamated questionnaire from existing NOS questionnaire items and from literature about common NOS misconceptions (Chen 2006). The researcher initially focussed on statements that reflected the following declarative tenets identified by Lederman and Lederman (2004a) as being central to NOS education;

- science is theory laden,
- science uses empirical evidence,
- human imagination and creativity influence scientific interpretation,
- social and cultural beliefs influence science,
- scientific knowledge is durable but tentative in nature,
- observation and inference are two distinct actions in science,
- scientific laws and theories are not hierarchical,
- the scientific method refers to a diverse range of careful data gathering techniques.

4.2. Selection of Items

The website, Assessment Tools in Informal Science (ATIS) (www.pearweb.org) lists multiple NOS related assessment tools. The researcher examined each listed tool to identify items that probed the ideas listed above and collated items for each of the eight tenets. In addition the A+Education, BREI, ERIC and Proquest databases were searched using the following terms "NOS questionnaire", "NOS Assessment", "epistemology questionnaire", "epistemology assessment" and "NOS research". Epistemology was used as NOS tenets can be considered to be a domain specific part of an individual's epistemological framework.

The search included peer-reviewed articles and published theses to include a wide range of evidence supported source materials. The researcher also reviewed the cited sources of each article and recent articles that were listed by the database as having since cited the work. A search was also made of each journal in which a relevant article appeared, using the same search terms, to identify any additional NOS articles that may not have appeared via the database searches. The resulting NOS tools examined included; Nature of Scientific Knowledge (NSKS) (Rubba & Andersen, 1978), Epistemological Questionnaire (EQ) (Schommer, 1990), Views on Science-Technology-Society (VOSTS) (Aikenhead & Ryan, 1992), Beliefs about Science and School Science Questionnaire (BASSSQ) (Aldridge, Taylor, & Chen, 1997), VNOS (Lederman, et al., 2002), Views on Science and Education (VOSE) (Chen, 2006), Characteristics of Science (CSQ) (Talbert, 2007), Views Of Scientific Inquiry VOSI (Schwartz, Lederman, & Lederman, 2008), and Scientific Epistemological Views (SEV) (Tsai & Liu, 2005).

In addition to searching existing assessment tools, the researcher also used articles about known NOS misconceptions and key NOS concepts (McComas & Olsen, 1998, Osborne et al., 2003 and Lederman & Lederman, 2004b) to generate potential items. The researcher generated potential items by taking key statements and either writing them as informed or naive statements about the specific NOS tenets.

The researcher pooled together a minimum of three naive statements and three informed statements about each of the eight concepts identified by Lederman (see section 2.2). The statements were modified if needed to ensure they probed students' understanding of professional scientific practice as students are known to hold different beliefs about classroom science and professional science (Sandoval, 2005). The researcher reviewed the resulting items with the assistance of a visiting professor with expertise in epistemology and questionnaire design who helped the researcher identify the most appropriate items and tenets for use in a questionnaire. Based on this discussion the researcher reduced the initial eight tenets to five (see section 3.4.4);

- *Tentative NOS*; students' beliefs about the tentative nature of scientific knowledge and the limits on the absolute certainty of scientific explanations
- *Law and Theory NOS;* students' beliefs about the roles and relationships between law and theory
- *Social NOS;* students' beliefs about the role of social influences in scientific research and practice.
- *Scientific method NOS;* students' beliefs about the nature of the scientific method
- *Empirical Evidence NOS;* students' beliefs about the role of empirical evidence in science.

Using this framework the researcher created an initial draft of the questionnaire for testing with fellow post graduate education students to help to identify statements that contained terminology and language issues that may have been too complex or ambiguous for year 11 students to comprehend (Fang, 2005; Fleer & Robbins, 2003). The review process also identified grammatical, comprehension and validity issues about the items that the researcher had overlooked. From this a feedback a second version of the questionnaire was created and trialled in a pilot study prior to the study proper (see Chapters 5 through 8).

4.3. Response scale development

The researcher also examined potential response formats to identify the one most appropriate for use in this research. The established literature in epistemology often uses a forced choice format to categorise participants' knowledge beliefs. The names can vary but they are often referred to in NOS as naive, transitioning or informed, though alternatives such as absolutist and evaluativist are common (see section 2.3) (Hofer & Pintrich, 1997; Kuhn, Iordanou, Pease, & Wirkala, 2008; Kuhn & Weinstock, 2002). This forced dichotomy between naive and informed positions with a transitional phase between the two positions is a dominant model in analysing the data collected in epistemology related studies including much of the NOS research in recent years. While this format has been useful in generating an overview of beliefs, it was potentially too coarse to capture the variety of beliefs that the literature review had lead the researcher to believe existed about NOS. In order to identify finer detail about the variety of student beliefs the researcher focussed on the use of a continuous response format (CRF), rather than a dichotomous format for this study.

The most commonly used form of a CRF scale in social research is the ordinal Likert scale mostly due to its ease of use (Noel & Dauvier, 2007). However, criticism of the Likert scale has revolved around its limited choice nature, the sensitivity of the changes it can measure and issues of acquiescence bias. While five and seven point Likert scales are common in most research, Preston and Colman (2000) concluded that seven to ten point ordinal scales are most reliable noting that scales beyond ten began to lose test/re-test reliability. Preston and Coleman also noted that scales with nine or more points provided the greatest measures of discrimination and validity. However, they recommended that their results indicated that the choice of scale was dependent on the purpose of the measurement.

Following private correspondence with the visiting epistemology expert the practicality of using a CRF known as visual analogue scale (VAS) was investigated. This response format allows students to mark a position on a 100ml line between two extreme poll positions in the place they feel is most appropriate. This differs significantly from typical Likert formats where response positions are dictated to participants by the researcher. Albaum, Best and Hawkins (1981) supported the use of such scales by concluding that VAS's and five point Likert scales captured equivalent data. Preston and Colman's study (2000) also included a 101 scale (a form of VAS) that performed well against the seven to ten point Likert formats and participants identified it as the format on which they could most accurately express their feelings. Such CRF formats provided two potential advantages over ordinal Likert formats for this study. First, VAS provides data that is nominally considered to be continuous rather than discrete which matches an underlying assumption of factor analysis calculations and allows the response format to be taken as a scale response for calculation purposes (Noel & Dauvier, 2007). This enhances the potential validity of any emergent categories that are derived from the participants' responses as opposed to Likert formats where the pre-existing response categories needed to be coded into a scale by the researcher (Carifio & Perla, 2007). Second, a VAS format can provide finer grain data than coarser Likert formats (Noel & Dauvier, 2007).

While the VAS format provided these advantages, other concerns existed about the practicality of the format for use in this study. The reliability on test/ re-test measures of such formats is not as high as seven to ten point Likert scales (Preston and Colman, 2000). This introduces errors that may result in individuals giving inconsistent responses to related items that may be interpreted as changes in the participants' beliefs or the probing different constructs if the sample size is not large enough. This is particularly important in this study as each tenet had six to eight items with students expected to provide consistent responses to both naive and informed items for a given tenet. This type of format also required each response to be individually measured and recorded, with an arbitrarily decided degree of accuracy (e.g., +/- 0.5mm) and potentially complex mathematical models needed to establish scale boundaries and standard errors (Noel & Dauvier, 2007). In addition Laerhoven, Zaag-Loonen, and Derkx (2004) compared VAS and Likert formats with children and noted that VAS formats were highly subjective and better for individual analysis rather than for group comparisons. Finally, the time needed to train participants so that they consistently and accurately respond to the items on a VAS format is considerable (Gould, Kelly, Goldstone, & Gammon, 2001).

Based on the limited time available with students, the screening intent of the questionnaire and the review by Preston and Coleman (2000) the researcher identified a nine-point Likert format as the most appropriate compromise of participant choice and ease of administration. The Likert response format response was anchored at each end by strongly agree and strongly disagree positions spaced equal distance from a middle neither agree nor disagree position. Between these three positions the remaining odd numbered responses were labelled while the even points left unlabelled so students had a greater degree of response options (see Table 4.1). The researcher deemed an odd numbered ordinal response format, as the best compromise between ease of data handling, the amount of detail recorded, and the reliability and repeatability of the data gathered by using multiple tenet items. This format was set up for the initial pilot study but remained subject to change based on the feedback of the participants of the pilot study (see section 6.3.6).

To allow the data to be analysed the response format was coded to a numerical scale. As the researcher had no empirical data on which to base a judgement about the magnitude of the units between the two anchor points of the response format (Carifio & Perla, 2007), a linear scale was used so that each Likert response was converted to a number between 1 and 9. For each item the most naive response was scored as a 1 and the most informed response scored as a 9 with response format positions between these two anchor points scored along a linear scale (e.g., a neither agree nor disagree response was scored as a five).

Table 4.1

Nine-point Likert scale selected for use with questionnaire.

Strongly agree		**Agree**		**Neither agree nor disagree**		**Disagree**		**Strongly disagree**
1	2	3	4	5	6	7	8	9

The decision to use a Likert format ultimately reflected the intention of the questionnaire to act as a screening device to identify students for interviews about the NOS tenets. The researcher expected any mechanical limitations of this choice on the statistical calculations to be minimal compared to differences between tenet clusters and it was not expected to hinder the selection of students for interviews.

Following the development of the NOS questionnaire it was trialled and modified over the course of two pilot studies with statistical analysis and feedback from students and national NOS experts used to improve the items developed and to inform the choice of the Likert scale. In the first pilot study a focus group was used to explore items that statistical analysis and student written feedback identified as problematic or confusing. The details of the methodology of the first pilot study are given in chapter 5 and the analysis of the statistical data and the focus group input are examined in chapter 6. The resulting modified questionnaire was then trialled in the second pilot study which is detailed in chapter 7 (methodology) and chapter 8 (results).

CHAPTER 5 – PILOT STUDY ONE

Introduction

The paramount concern in the development of NOS questionnaires is the interpretability and meaningfulness of items to the participants (Chen, 2006). The pilot studies ensured the questionnaire items were interpretable and meaningful to year 11 students. The data from Pilot Study One was analyzed and used to identify potentially problematic items, which were discussed with students in a focus group. Student input was used to revise the questionnaire items and the revised version was given to a different sample of students in Pilot Study Two.

The students in Pilot Study Two took part in a class discussion to identify any remaining items which were potentially problematic. The response data was analyzed and used to identify what aspects of the questionnaire would be examined with the purposively interviewed students in the study proper. Further, to ensure the face validity of the statements, three national experts with experience in NOS evaluated the validity of the items. The resulting NOS questionnaire was then used in the first phase of the study proper to test possible factor solutions to explain the responses of the students and to purposively select students to participate in semi-structured interviews about their NOS beliefs.

Method: Pilot Study One

The modified NOS items were trialled with a class of year 11 students during a regular science lesson. Students were encouraged to identify items they found confusing or were unsure of. The written annotations, along with a statistical analysis of the data, were used to direct a focus group discussion with six students from the class who provided feedback on the items. A revised NOS questionnaire was then developed and used in Pilot Study Two.

5.1. Participants

Pilot study one included 25 students (16 male, 9 female, median age 15) from a single mainstream science class at a decile seven lower North Island school in New Zealand. Decile ratings are used by New Zealand's Ministry of Education to rank the socio-economic circumstances of the majority of students at a school in order to determine funding assistance. The lower the decile rating the more additional funding a school receives. Ten deciles exist with each decile contains approximately 10% of the schools in New Zealand (Ministry of Education, 2011).

From the class, six students (3 male and 3 female) were selected to participate in the focus group discussion. The students selected included one male and one female student whose overall questionnaire responses were scored as high, medium and low in order to include the responses from a variety of students.

5.2. Materials

5.2.1. Questionnaire.

Version two of the questionnaire (see Appendix A) contained 35 randomly ordered informed and naïve items that were based on the review of existing NOS questionnaires and NOS literature (see section 4) and were intended to probe the five NOS tenets outlined in the instrument development section (see section 4.1). A minimum of six items were used for each tenet to with additional items retained so that the most appropriate items could be selected based on empirical data (see Appendix D and section 6.3.8 for a list of pilot study items ordered by NOS tenet). The NOS tenet items consisted of:

Tentative NOS. Seven items were used to probe students' beliefs about the tentative nature of scientific knowledge. Three items were written to measure informed beliefs (e.g., Science can never determine absolute truth), and four items were written to measure naïve beliefs (e.g., Scientific explanations are absolutely correct).

Law and Theory NOS. Eight items were used to probe students' beliefs about the roles and relationships between law and theory. Four items were written to measure informed beliefs (e.g., New evidence changes scientific laws), and four were written to measure naïve statements (e.g., Scientific laws are fixed and work everywhere).

Social NOS. Eight items were used to probe students' beliefs about the role of social influences in NOS. Four items were written to measure informed beliefs (e.g., Personal beliefs influence scientific observations), and four were written to measure naïve statements (e.g., Personal values do not influence science).

Scientific method NOS. Six items were used to probe students' beliefs about the nature of the scientific method. Three items were written to measure informed beliefs (i.e., Scientific experiments can never be measured exactly), and three items were written to measure naïve beliefs (e.g., Scientific experiments produce precise, accurate results).

Empirical Evidence NOS. Six items were used to probe students' beliefs about the role of empirical evidence in science. Three items were written to measure informed beliefs (e.g., Scientific explanations are based upon evidence), and three items were written to measure naïve beliefs (e.g., Scientific explanations do not need evidence).

The participants responded to each item on a nine-point Likert scale (1 = strongly agree to 9 = strongly disagree). Seventeen items were meant to reflect informed beliefs, whereas 18 items were meant to reflect naïve beliefs. During the data input stage, the 17 informed statements were reverse coded such that responses reflecting informed beliefs received a higher score (i.e., strongly agreeing with tentative NOS item "Science can never determine absolute truth" was scored as a 9), whereas responses reflecting naive beliefs received a lower score (i.e., strongly disagreeing with the law and theory item "If a scientific theory is proven right it becomes a scientific law" was scored as a 1). The data for the 18 naive statements was entered unchanged. A score over five indicated an informed belief about the NOS statement presented while a score under five indicated a naïve belief about the statement. A score of five indicated that the student had taken a neutral position to the statement. The summed responses to all of the items could range from 35 to 315.

5.2.2. Focus group sheet

The focus group participants were given a question sheet and their completed questionnaire to act as cues to help them in the discussion. The items on the question sheet were organized by NOS tenet, but were not labelled so that the students could only use the content of the statements to decide if they were related. For each tenet the sheet asked the students to review the items and to identify which items they believed were related to each other and which items they believed presented conflicting views. The sheet also asked specific questions based on the annotated comments that students had made about particular items and items that the researcher had identified as statistically aberrant during the data analysis stage (see Appendix D).

5.3. Procedure

5.3.1. Questionnaire administration.

The questionnaire was administered during the students' regular science lesson. Prior to distributing the questionnaire, the researcher explained to the students that the purpose of the study was to ensure the comprehensibility of the questionnaire items. The researcher also informed the students that participation in the pilot study and focus group was entirely voluntary. The students were asked to respond to the questionnaire items based on their own beliefs about science and were informed that there were no right or wrong answers. The students were asked to annotate with question marks or comments any items that they found confusing. They were given 30 minutes to complete the questionnaire.

5.3.2. Focus group administration.

Focus groups provided a forum in which groups of individuals can discuss topics that are not part of their normal discourse (Merriam, 2009). Focus groups allow participants to socially construct relevant knowledge involving concepts that are not personally sensitive (Merriam, 2009). Six students were selected for the focus group based on their overall questionnaire scores. The focus group met during the students' regular science lesson the week after they had completed the questionnaire. At the start of the session the students were informed that participating in the group was entirely voluntary. The researcher explained to the students that the purpose of the focus group was to identify and modify any items that had been difficult to comprehend. The students were then given a copy of the focus group question sheet and their completed questionnaire which they used as guides during the discussion with the researcher.

When the students identified an item as difficult to interpret, the researcher explained the reason for using the item, and then with the students' assistance an alternative wording for the item was attempted. If the focus group could not agree on an appropriate way to word an item, it was removed. The items associated with each tenet were discussed in turn and the researcher made written notes during the session of issues raised by the students and changes made to the items.

5.4. Data Analysis

The students' annotations on the questionnaires were recorded to identify the items that students found confusing. The questionnaire responses were entered into an Excel spreadsheet and spot checks were completed to ensure the fidelity of the data transfer before the informed items were reverse coded to ensure a high score was indicative of an informed response and a low score was indicative of a naïve response for all 35 items. A cumulative score for each student based on all 35 items was then calculated and used to identify one male and one female student who represented high scoring (one standard deviation above the mean score), mid-range scoring (within one standard deviation of the mean score) and low scoring (one standard deviation below the mean score) students to take part in the focus group.

The data was further analyzed using PASW 18 software. The researcher examined the reliability (i.e., Cronbach's alpha), corrected item-total correlations and descriptive statistics for the items from each tenet to identify specific items or tenets that were not answered consistently and appeared to have interpretation issues. This tested the assumption that the items were correlated to the same subscale (i.e. the particular tenet). One paper was excluded from the analysis when an obvious patterned response set (i.e., zigzag) was detected in the response data.

Cronbach's alphas were used to measure the internal consistency of items within each NOS tenet subscale. Alphas above .7 indicated an acceptable level of consistency across the tenet subscale items (Streiner, 2003a, 2003b). Any item that when removed raised the alphas above the .7 threshold was identified by the researcher as an item to discuss with the focus group. When a subscale's alpha remained below .5 after items were removed, the NOS tenet was included in the focus group discussion. For tenets with alphas greater than .5, the items were further examined using the corrected item-total correlation. The threshold for item correlation is dependent on the breadth of the characteristics being measured (Streiner, 2003b). It is recommended that the threshold for a broad characteristic is .15 to .20 while that for narrower characteristics is .40 to .50. For the pilot study a minimum of .3 was used to identify weakly correlated items which were discussed with the focus group. The descriptive statistics for the weakly correlated items were also examined to identify characteristics that might help provide a substantive reason for why the items did not correlate as well as expected. The descriptive statistics of the remaining items were also examined to identify items that had statistics that were notably different from other correlated items. The findings of this analysis were then used to help guide the focus group discussion on the items and the NOS tenets.

The next section describes the implementation of this analysis and the data revealed from the analysis of the student annotations and statistical results. It then describes how the focus group responded to this data and the insights this revealed into the differences between student interpretations of items and those intended by the researcher.

CHAPTER 6 – PILOT STUDY ONE RESULTS

Introduction

This chapter describes the analysis of the student annotations of the questionnaire (section 6.1), the descriptive statistical analysis conducted with the limited sample size available (section 6.2), and the feedback from the focus group participants (section 6.3). The section concludes with a summary of the changes to the items as a result of the insights gathered from the pilot study participants.

6.1. Annotations

The researcher examined the 25 questionnaire sheets for student annotations and the following comments were noted:

- Ten students identified a typing error in social NOS item eight.
- One student question marked social NOS item five and made the comment "sounds difficult". This student also annotated the response column 'neither agree/disagree' with "kinda - don't know/don't care" and on the bottom of the final page made the comment "don't know what some meant".
- One student question marked law and theory NOS item five and social NOS item one. They also marked social NOS item five circling the word 'neutrally' and social NOS items six circling the word 'explanations'.
- One student placed an asterisk beside scientific method NOS item one.

6.2. Descriptive Statistics

Each tenet subscale was analyzed using PASW 18 software. Descriptive statistics were used to identify items that did not appear to be answered consistently with other items on the subscale.

6.2.1. Tentative NOS concepts

The Cronbach's alpha for the seven tentative NOS items was an acceptable .70, which was not substantially improved by the removal of any item (see Table 6.1a). This indicated the items had an acceptable level of internal consistency. The corrected item-total correlation for items one, three, five and seven were all at an acceptable level (above .3) but items two, four and six were notably lower indicating that they were only weakly correlated to the other items in the tentative NOS tenet subscale.

Table 6.1a

Item statistics for tentative items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Tent1	.52	.63
Tent2	.18	.71
Tent3	.65	.60
Tent4	.15	.73
Tent5	.55	.63
Tent6	.28	.70
Tent7	.59	.62

The mean for item two was notably higher than the means of the other items in the subscale (see Table 6.1b). When examined, 83% of the participants had agreed with this item and the remainder had elected to adopt a neutral position. Item two was selected for further discussion with the focus group because it elicited such a high proportion of informed responses and had been only weakly correlated with the other items.

Item six had a relatively acceptable item-total correlation, but like item two it had a comparatively high proportion of students responding to it in an informed way. As a result, the item was also selected for discussion in the focus group. Item four was also selected for the focus group discussion because it had the lowest mean of the tenet subscale with 75% of the participants responding to the item in a naïve way.

Table 6.1b

Descriptive statistics for pilot study tentative item

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Tent1	7	2	9	6.08	2.22	-0.29	-1.00
Tent2	4	5	9	6.83	1.24	0.19	-0.58
Tent3	7	2	9	5.54	1.79	-0.17	-0.65
Tent4	8	1	9	3.67	1.83	1.23	1.91
Tent5	5	4	9	5.96	1.68	0.79	-0.51
Tent6	8	1	9	6.17	1.79	-1.02	1.96
Tent7	7	2	9	5.13	1.60	-0.08	0.81

6.2.2. Law and theory NOS concepts

The Cronbach's alpha for the eight law and theory NOS items was low (-.21), which indicated a weak correlation existed between the items, and therefore unacceptable. The alpha value was not improved by the deletion of any item (see Table 6.2a). When the descriptive statistics were examined it was noted that the informed and naïve items had notable differences between the means of the first four informed items and three of the naïve items. When the informed and naïve items were separated into two separate subscales (i.e. the tenet was not considered the unifying structure), the Cronbach's alpha for the informed items was .55 and for the naïve items was .37. As the values remained below the acceptable threshold, the law and theory tenet and all the items associated with it were identified as needing to be reviewed with the focus group.

Table 6.2a

Item statistics for law and theory items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Law1	-.05	-.19
Law2	-.10	-.15
Law3	.16	-.48
Law4	-.06	-.19
Law5	-.33	.05
Law6	.03	-.30
Law7	-.11	-.12
Law8	-.05	-.19

Table 6.2b

Descriptive statistics for pilot study law and theory items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Law1	4	5	9	6.38	1.06	-0.61	-0.45
Law2	5	4	9	6.25	1.15	0.21	0.09
Law3	5	4	9	6.79	1.59	0.23	-1.19
Law4	8	1	9	6.63	1.84	-1.37	2.51
Law5	5	1	6	3.75	1.3	-0.28	-0.76
Law6	7	2	9	4.71	1.71	0.61	0.17
Law7	8	1	9	6.58	1.67	-1.42	4.64
Law8	5	1	6	3.83	1.34	-0.02	-0.53

6.2.3. Social NOS concepts

The Cronbach’s alpha for the social NOS items was .57 which improved to an acceptable .74 when item five was deleted (see Table 6.3a). As item five had a negative item-total correlation and its skewness and kurtosis values were comparatively high, it was identified as a specific item to discuss with the focus group. Item six also had a negative item-total correlation though its descriptive statistics were consistent with the remaining items. As no clear reason was identified for its weak correlation, it was also selected as an item to discuss with the focus group.

Table 6.3a

Item statistics for social items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Soc1	.64	.40
Soc2	.17	.57
Soc3	.86	.28
Soc4	.65	.43
Soc5	-.51	.74
Soc6	-.22	.65
Soc7	.52	.44
Soc8	.31	.53

Item two had a low item-total correlation though it did not have an effect if deleted. Its descriptive statistics were notably different with a higher mean than the other items. As 79% of the students responded to the item in an informed way it was identified as an item to discuss with the focus group. For the remaining items it was noted that a high proportion of students selected the neutral option in response to many of the correlated social NOS items and this trend was identified as an issue to discuss with the focus group.

Table 6.3b

Descriptive statistics for pilot study social items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Soc1	8	1	9	5.88	2.05	-.61	.20
Soc2	7	2	9	6.67	1.69	-.79	1.28
Soc3	8	1	9	6.33	2.20	-.54	-.43
Soc4	7	1	8	5.38	1.64	-.54	1.21
Soc5	8	1	9	4.00	1.77	.82	1.82
Soc6	6	3	9	5.92	1.50	.32	-.13
Soc7	8	1	9	4.92	2.10	.15	-.26
Soc8	8	1	9	5.92	2.04	-.31	.04

6.2.4. Scientific method NOS concepts

The Cronbach's alpha for the scientific method NOS items was a near acceptability .69, and only slightly improved when item two was deleted (see Table 6.4a). Item two had an item-total correlation below the .3 threshold but as deleting the item did not alter the relative value of the alpha it was not identified as needing to be further examined.

Table 6.4a

Item statistics for scientific method items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Meth1	.56	.60
Meth2	.23	.70
Meth3	.45	.66
Meth4	.58	.59
Meth5	.34	.69
Meth6	.48	.64

None of the items had high kurtosis and skewness values though they had notable variations in their means and standard deviations. Only item six was identified as needing to be specifically discussed with the focus group as 33% of the students had selected the neutral category in response to that item.

Table 6.4b

Descriptive statistics for pilot study scientific method items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Meth1	6	3	9	5.71	1.85	0.29	-0.72
Meth2	4	5	9	6.67	1.37	0.33	-1.06
Meth3	4	5	9	7.04	0.95	-0.09	-0.37
Meth4	8	1	9	4.75	1.96	0.12	-0.08
Meth5	8	1	9	5.25	2.05	-0.37	-0.02
Meth6	6	3	9	5.75	1.39	-0.04	0.41

6.2.5. Empirical evidence NOS concepts

The Cronbach's alpha for the empirical evidence items was an unacceptable -.69 but this improved to .47 when item one was excluded. When item one was maintained in the item statistics the item-total correlation showed that none of the items meet the .3 threshold for acceptable correlation (see Table 6.5a). Since item one had a large effect on the item statistics it was identified as an item to be explicitly discussed with the students in the focus group.

As alpha values when items were deleted were large and negative, the analysis was re-run with item one removed (see Table 6.5b) so that the relationships of the other items could be examined without the distortion of item one. The item-total correlations indicated that item four was negatively correlated to the other items, and if deleted, improved the alpha to a near acceptable level. Item six was also only weakly correlated to the remaining items but did not change the relative value of the alpha if deleted.

Table 6.5a

Item statistics for empirical evidence items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Emp1	-.71	.47
Emp2	.23	-1.40
Emp3	.12	-1.38
Emp4	-.36	-.31
Emp5	.20	-1.38
Emp6	-.01	-1.06

Table 6.5b

Item statistics for empirical evidence items excluding empirical item 1

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Emp2	.54	.22
Emp3	.56	.14
Emp4	-.36	.69
Emp5	.47	.26
Emp6	.18	.48

The mean and standard deviation of item four was notably different to the remaining items. All the participants agreed with the naïve item four and so it was identified as an item to explicitly discuss with the focus group students. While item six did not affect the alpha, 38% of students had opted for the neutral category in response to this item. The high level of uncertainty compared to the other items meant item six was also identified as an item to discuss with the focus group.

Table 6.5c

Descriptive statistics for pilot study empirical evidence items

	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Emp1	6	1	7	3.13	1.70	.25	-.53
Emp2	4	5	9	6.75	1.11	.13	.06
Emp3	7	2	9	6.79	1.38	-1.64	5.74
Emp4	3	1	4	2.88	.99	-.31	-1.01
Emp5	4	5	9	7.58	1.18	-.65	.12
Emp6	7	2	9	4.88	1.51	.81	1.41

6.3. Focus Group Discussion

Each NOS concept was discussed with the focus group students and the items and tenets identified as problematic in the statistical analysis and in the student annotations were explicitly discussed. The descriptions below summarize the discussion and detail the changes that were made to the questionnaire as a result of student input.

6.3.1. Tentative NOS concepts

As students had not made any annotations on the tentative tenet items and the alpha had been an acceptable .7, only the weakly correlated items (i.e., items two, four and six) were set to be explicitly discussed with the focus group.

The students in the focus group did not identify any of the items in this theme as being unusual or out of place and did not immediately identify any of the items as being difficult to interpret. Of the three informed items, only item 1 was changed. The initial wording “New evidence changes scientific explanations” was revised to “New evidence can change scientific explanations.” The researcher suggested this change to the students based on the comments of the national NOS expert who had completed the questionnaire prior to the pilot study. The students agreed that the change would make the statement more explicit but did not feel that any other changes were needed to the item.

The researcher had examined the fourth item prior to conducting the focus group and the term “natural world’ had been identified as unique to this tentative item. The students were asked what they thought the term meant and one student stated they had thought it excluded manmade objects, while another stated that they thought it referred to biology. As the term did not appear to be well understood, the idea behind the term was discussed with the students. From the ensuing discussion it was decided that the term ‘world around us’ should replace ‘natural world’ in the questionnaire as the students felt this term better captured the wider context of what science investigated (see Table 6.6a).

In discussing item six, the focus group asked why the term ‘established’ had been used with item six but not with item five. When the researcher asked them what they thought “established scientific explanation” meant, the students stated that they understood the term to mean the sort of explanations they would expect to find in science textbooks. The students suggested that item five also needed to have the word established added to it in order to make the item more consistent with item six.

6.3.2. Law and theory NOS concepts

One student had annotated law and theory item five during the administration of the questionnaire and the entire tenet subscale had produced an unacceptable Cronbach’s alpha. The broad concepts involved in the subscale were first discussed with the focus group before specific items were examined.

In reviewing the law and theory tenet, the students immediately stated that they did not recall explicitly encountering the terms ‘law’ or ‘theory’ in class and so had been uncertain about the subsequent statements. This revelation prompted the researcher to pay particular attention to law and theory concepts in the study proper, and as described later, proved to be a major factor in the NOS beliefs of the students who were interviewed. As students in the focus group were uncertain about the terms, the researcher gave them a brief description of the terms based on the definitions outlined in the literature review (see section 2.2.) so that they could contribute to an informed discussion about the items.

Once the students were comfortable with the two terms, the individual items were reviewed. Students stated that item seven was confusing and that its point was unclear. Following a discussion on the statement's intended meaning and students' interpretation of what it meant, it was agreed that the item should be removed. The researcher later replaced the item with the direct NOS misconception statement "scientific laws exist in nature before we discover them" (see Table 6.6b). The focus group also noted that item eight was too long and confusing. The item was removed and an altered version of item five "scientific theories become scientific laws when enough evidence is collected" was added to replace it.

While the lack of explicit knowledge of the terms law and theory had been a primary issue with these items, the use of the term natural world in item two was also noted as causing additional confusion. To make the statement consistent with the change made to the tentative item it was altered to read "scientific laws are created to describe observations made about the world around us." The students also stated that the term 'patterns in data' used in item one was too obscure and so the statement was changed to read "scientific theories are created to explain patterns in the world around us." The students did not identify any of the remaining items as needing changes. The researcher attributed the annotated question mark on item five to the lack of explicit knowledge about laws and theories that the focus group had raised.

6.3.3. Social NOS concepts

Students had annotated social items one, five and six during the administration of the questionnaire. The deletion of item five also raised the alpha for the subscale above the .7 threshold while items six and two had item-total correlations below .3. The items in this tenet subscale also had a high proportion of students selecting the neutral category in response to these items.

The focus group identified only two of the social NOS items as needing changes. The students immediately noted that item five was inconsistent with the other items in the group. The item was not able to be modified in a way which the students felt was consistent with the other item and so it was removed and the researcher later replaced it with the NOS misconception "Scientific research is not affected by personal beliefs" (see Table 6.6c).

The focus group students also identified item seven as being open to a number of interpretations. During the discussion about the concept behind the statement, it was agreed that the statement should be made more specific and the item was changed from "Personal values and goals do not influence science" to "Personal values and goals do not influence the way scientific evidence is interpreted."

As noted in the statistical analysis, a number of these items elicited neutral responses (i.e., 42% of participants selected the neutral category for items four and eight). During the discussion with the focus group it became clear that students were not sure that beliefs should or would affect scientists. The students stated that their perceived lack of experience with authentic science meant they did not know whether the statements were accurate. With the exception of item five, which was subsequently changed, the students confirmed that the items had a consistent theme, but that their lack of experience with 'real science' meant they were uncertain whether the items were accurate.

6.3.4. Scientific Method NOS concepts

Only one student had annotated a scientific method item and the subscale had a near acceptable alpha of .69. Item six was noted during the data analysis for discussion as 33% of students had selected the neutral category in response to this item.

Despite this group of items having an acceptable alpha the discussion with the focus group indicated that they had had considerable issues with these items. As with the social NOS items the students stated that their lack of experience with authentic science meant that they were uncertain about what scientists actually experienced. The students stated that they perceived their classroom experience with experiments and data as being very distinct from that of scientists and that some had responded to the statements based on their classroom experience while others had responded based on what they perceived actual scientific practice to be.

For item one and four the researcher asked whether adding the term 'professional' to the start of the statements would help clarify which version of science, classroom or authentic, students should be answering about. The students agreed that this would help focus the items and also suggested that in item four the terms 'precise' and ‘accurate’ seemed to be redundant. After the researcher explained the concepts of precise versus accurate results the students stated that the distinction was not something that they were used to and so the item was altered to “professional scientific experiments produce exact results.”

The students identified item two as confusing as they were not sure what idea it was trying to capture. Following a discussion on the item it was then simplified to read “There is no single scientific method.” Item three was also identified as confusing and after a brief discussion it was reworded to read “Many different scientific methods are used to solve scientific questions” (see Table 6.6d).

Item five was identified as being extremely problematic. The additional clause at the end of the statement ‘unless a mistake is made’ was identified by the students as confusing. Several attempts were made to reword the statement but the students did not identify any alteration as being a significant improvement. The item was removed and later replaced with the NOS misconception “The scientific method refers to the steps all scientific experiments follow” by the researcher.

For item six the students wondered why the term culture had been used and stated that they had no idea if other cultures treated science in the same way. This was a particularly vexing response given the attempt to include Maori (indigenous New Zealand) culture in the curriculum and the efforts of educators to include Maori science in their classroom practice. When the idea was pressed with the students, it became apparent that while they may have encountered Maori science at different stages of their education they had not perceived it as being different to western scientific practices. As the statement did not appear to probe the intended concept it was removed and replaced by the NOS misconception “There is one scientific method that is always used in the same way”. The issue of distinct cultural science practices was set aside to be pursued in the interview phase of the study proper where it could be examined in more detail.

6.3.5. Empirical Evidence NOS concepts

While no annotations were made on the empirical evidence items the Cronbach’s alpha for the tenet was unacceptable. Item one was identified as being a major contributor to the items failing to correlate. Items four and six were also noted as having weak item-total correlations.

The focus group restated that item one had been an issue as the term ‘natural world’ was associated with natural or biological phenomena and the students had recognized that science was able to investigate a much wider range of phenomena. The students agreed that the term should be replaced by the term ‘world around us’ to keep it consistent with the other items.

Participants in the focus group identified item four as an informed item. The item had been intended to probe misconceptions about the relationship of evidence and explanations. In discussing the item with the students it became clear that the item was not probing the misconception that was intended and, with guidance from the students, the item was altered and simplified to read “scientific explanations are created before data is collected.” Item five was also altered to be more explicit and was changed to “Scientific explanations do not need evidence to be accepted.”

Item six was the last item the students identified as needing to be changed. The focus group stated that the item was confusing and that they had had trouble interpreting what the item meant. The statement was subsequently removed and the researcher replaced it with a naïve version of item two (see Table 6.6e)

6.3.6. Likert scale

The researcher also asked the focus group if the Likert scale used was an appropriate response format for the questionnaire. The group responded that they felt the 9 point scale used was appropriate and that they liked that they could select options between the stated positions which they used when they were not as confident about what response to use for an item. The students liked that they could provide written feedback on the questionnaires to qualify their responses and consequently the researcher encouraged students to add annotations to the questionnaire throughout the remainder of the study.

6.3.7. Additional issues

Overall, participants in the focus group revealed that they felt they lacked the suitable experience with real science to allow them to answer many of the statements with any degree of certainty. The students explained that for many of the items they had opted for the neutral position because they had no idea if the statement was an accurate representation of the way science operated. The students also noted that the tentative and socially influenced statements about science did not match their experiences of science which they perceived to be more fact driven and universal in application. These particular experiences and opinions were not pursued in depth with the focus group students as the discussion was focussed on ensuring the clarity and interpretability of the items; however they were carried over into the interviews conducted in the study proper.

6.3.8. Summary of changes

Based on the focus group discussion the following changes were made to the questionnaire. The tables below give the original items and then where appropriate give the altered version of the item.

Table 6.6a

Tentative NOS items

Item	Statement
Tent1	* Science can never determine absolute truth.
Tent2	Original: New evidence changes scientific explanations.
	Revised: New evidence *can change* scientific explanations.
Tent3	*No scientific explanation can be proven to be absolutely true.
Tent4	Original: The study of science finds out the absolute truth about the natural world.
	Revised: The study of science finds out the absolute truth about the *world around us*.
Tent5	Original: Scientific explanations are absolutely correct.
	Revised: *Established* scientific explanations are absolutely correct.
Tent6	*Established scientific explanations never change.
Tent7	*Science books contain absolutely true explanations.

Note: *Indicates no change was made to the original item wording.

Table 6.6b

Law and theory NOS items

Item	Statement
Law1	Original: Scientific theories are created to explain patterns in data. Revised: Scientific theories are created to explain patterns in *the world around us*.
Law2	Original: Scientific laws are created to describe observations made about the natural world. Revised: Scientific laws are created to describe observations made about the *world around us*.
Law3	*New evidence can change scientific laws.
Law4	*Scientific laws are temporary and change with new discoveries.
Law5	*If a scientific theory is proven right it becomes a scientific law.
Law6	*Scientific laws are fixed and work everywhere.
Law7	Original: There is no reason to question established scientific laws. Revised: Scientific laws exist in nature before we discover them.
Law8	Original: When many scientific theories exist, the correct one is identified when enough data is collected. Revised: Scientific theories become scientific laws when enough evidence is collected.

Note:*Indicates no change was made to the original item wording.

Table 6.6c

Social influence NOS items

Item	Statement
Soc1	*Personal beliefs influence scientific observations.
Soc2	*Scientific data can be interpreted in many different ways.
Soc3	*Values and beliefs influence scientific research.
Soc4	*Experience and beliefs affect the interpretation of scientific data.
Soc5	Original: Science neutrally assesses the risks and benefits of modern technology.
	Revised: Scientific research is not affected by personal beliefs.
Soc6	*Past explanations do not affect new scientific explanations.
Soc7	Original: Personal values and goals do not influence science.
	Revised: Personal values and goals do not influence *the way scientific evidence is interpreted*.
Soc8	*Personal beliefs do not influence scientific explanations.

Note:*Indicates no change was made to the original item wording.

Table 6.6d

Scientific method NOS items

Item	Statement
Meth1	Original: Scientific experiments can never be measured exactly. Revised: *Professional* scientific experiments can never be measured exactly.
Meth2	Original: The scientific method uses many different ways to collect data. Revised: There is no single scientific method.
Meth3	Original: The study of science uses many different scientific methods to answer questions. Revised: Many different scientific methods *are used to solve scientific* questions.
Meth4	Original: Scientific experiments produce precise, accurate results. Revised: *Professional* scientific experiments produce *exact* results.
Meth5	Original: Scientific experiments always get the same results unless a mistake is made. Revised: The scientific method refers to the steps all scientific experiments follow.
Meth6	Original: Scientific methods are the same in every culture. Revised: There is one scientific method that is always used in the same way.

Table 6.6e

Empirical method NOS items

Item	Statement
Emp1	Original: Scientific evidence only includes data about the natural world.
	Revised: Scientific evidence only includes data about the *world around us*.
Emp2	*Scientific explanations are created by interpreting evidence.
Emp3	*Scientific explanations are based upon evidence.
Emp4	Original: In the study of science evidence is found to prove an idea is correct.
	Revised: Scientific explanations are created before data is collected.
Emp5	Original: Scientific explanations do not need evidence.
	Revised: Scientific explanations do not need evidence *to be accepted*.
Emp6	Original: Scientific evidence is enough to establish if something is true.
	Revised: Scientific evidence does not need to be interpreted.

Note: *Indicates no change was made to the original item wording.

Following the modifications to the questionnaire a second pilot study was conducted to assess the appropriateness of the changes to the items and to identify if any remaining issues existed with the format and design of the questionnaire. The second pilot study also sought the input of national NOS experts as to the suitability of the items developed. The methodology of this second pilot study is detailed in chapter 7 and the qualitative and quantitative results of the student feedback and the NOS experts are examined in chapter 8.

CHAPTER 7 – PILOT STUDY TWO

Method: Pilot Study Two

Following the changes made to the questionnaire by the focus group, the revised version (see Appendix B) was administered to two new classes of students to determine whether any additional wording changes were needed. This questionnaire was subsequently reviewed by three national experts with NOS experience to ensure the items remained valid NOS statements. A statistical analysis was conducted on the questionnaire data and the findings used to inform the interview questions for the study proper.

7.1. Participants

Pilot study two included 50 students (median age 15) from two mainstream co-educational science classes in the same school that was used in Pilot study one. No further demographic information was collected about the students as only the comprehensibility of the items was being investigated with this pilot study.
The review panel comprised of three education experts who had expertise in NOS education.

7.2. Materials

7.2.1. Questionnaire

Version three of the questionnaire consisted of the 35 revised items. The informed and naive items for each subscale were randomly ordered throughout the questionnaire. The participants responded to each item on a nine-point Likert scale (1 = strongly agree to 9 = strongly disagree). The items were scored as per the method described in section 5.2.1.

7.3. Procedure

7.3.1. Questionnaire administration

The questionnaire was administered during the students' regular science lesson. Prior to distributing the questionnaire, the researcher explained to the students that the purpose of the study was to ensure the comprehensibility of the questionnaire items. The researcher also informed the students that participation in the pilot study was entirely voluntary. The students were asked to respond to the questionnaire items based on their own beliefs about science and were informed that there were no right or wrong answers. The students were asked to annotate with question marks or comments any items that they found confusing. They were given 30 minutes to complete the questionnaire.

7.3.2. Class discussion administration

Once each class had completed the questionnaire the researcher initiated a class discussion to identify any items that the students had found confusing. The student annotations were used as guides to identify items that needed to be addressed. The researcher also asked students in each class their opinions about the Likert scale used. The researcher took written notes during the discussions.

7.4. Expert Review

Following the final class discussion, the items were sent to three national judges with NOS expertise for review. These experts were sent the a review sheet of the items (see Appendix D) with the items grouped under their tenet heading and marked as naive or informed. They were asked to identify any items they felt were not valid NOS related statements and comment on the appropriateness of the classification of items in the respective subscales. The feedback from the experts was then reviewed and incorporated into the study proper.

7.5. Data Analysis

The questionnaire responses were entered into an Excel spreadsheet and spot checks were completed to ensure the fidelity of the data transfer. The informed items were reverse coded to ensure a high score was indicative of an informed response for all 35 items and a low score was indicative of a naïve response.

The researcher analyzed the data using PASW 18 software and examined the reliability (i.e., Cronbach’s alpha), corrected item-total correlations and descriptive statistics for the items from each tenet subscale. The Cronbach’s alphas were used to identify subscales with items that did not correlate as anticipated. Subscales with alphas below .6 were reviewed alongside the class discussion and focus group notes in order to establish possible substantive explanations for the failure of the items to correlate. As the sample size was too small to conduct a factor analysis, all the items that met the comprehension and validity requirements of the pilot study were maintained for the study proper so that they could be examined with a larger sample group.

CHAPTER 8 – PILOT STUDY TWO RESULTS

Introduction

This chapter describes the analysis of questionnaire data for the second pilot study which used the revised NOS questionnaire items. As less time was available for the second pilot study, a class discussion (rather than focus groups) was conducted following the administration of the questionnaire to elicit thoughts and concerns from the participants and to help identify any concerns noted by student annotations (see section 8.1). Feedback was also sought for the items from national NOS experts (section 8.2). Finally, a descriptive statistical analysis was conducted on the data to identify if the changes made as a result of the comments generated by the focus group helped resolve issues raised in the first pilot study (section 8.3). This chapter concludes with a summary of emergent themes raised by the pilot studies and reviews the research questions that the study proper set out to address.

8.1. Class Discussion

Year 11 students in New Zealand have year round assessments as part of the National Certificate for Educational Achievement (NCEA). Students and teachers consider the year-long internal assessment as high stakes assessment and are often unwilling to participate in research that they feel may reduce the time they have to spend on coursework. To make the most of the time available the researcher decided to conduct a class discussion with each class on the items immediately after the questionnaire was completed. The discussion focussed on two aspects, 1) did the students have any issues with interpreting the items and 2) did the students think the 9-point Likert scale was appropriate.

As only three students across the two classes annotated their questionnaires the researcher asked those specific students to clarify their annotations while collecting their papers. The first student, who had identified himself as a foreign exchange student at the start of the lesson, had marked eight of the items with question marks. When the researcher asked the student about the annotations he stated that he had been uncertain if the items were accurate. The student also circled the word established on tentative NOS item six. When the researcher asked the student why he had circled the word the student replied that he did not know what the word meant. This particular comprehension issue was then attributed to English not being the student's first language.

The second student wrote "not sure" beside law and theory item six and social item six. When the researcher asked the student about these items, the student stated it was because they were unsure if the items were accurate reflections of science. The students had not had an issue in understanding the wording of the items.

The final student had made clear self-explanatory annotations beside several statements. Beside tentative item eight ("Science books contain absolutely true explanations") the student wrote "depends on how old they are". The student also annotated two of the social NOS items. Beside the first social item ("Personal beliefs influence scientific observations") the student wrote "it can" and beside the third item ("Values and beliefs influence scientific research") the student wrote "they shouldn't". In each case the annotations showed that the student had clearly understood the items and was providing an explanation for the response choice.

Aside from the annotations none of the students in the either class identified any of the items as being difficult to comprehend. Their general response was similar to that of the focus group in that they felt they lacked experience with authentic science to accurately respond to some of the items included in the questionnaire. A difference between the focus group and class discussion was that the students involved in the class discussion only saw the statements in a randomized order and so could not comment on how well they thought the items reflected the specific NOS tenet subscales.

In response to the use of the 9 point Likert scale the students in both classes felt that the scale had given them an appropriate range of response options to express their beliefs about each item. They did not recommend that it should be reduced to a seven or five point scale. All the students agreed that the neutral option was needed in order to capture their beliefs especially for the items they felt they lacked the experience to answer accurately.

8.2. Expert Review

As the students in the classes had not identified any comprehension issues with the revised items they were then sent to three national judges with NOS expertise who were asked to review the items and judge if they maintained their validity as appropriate NOS statements. Two of the experts questioned the need for another NOS questionnaire "I wonder why you want to make another when there are so many out there already"

(Expert A). They also warned of the potential that such a questionnaire would only lead to more deficit literature on NOS education. Despite this the reviewers agreed that the items were appropriate, worded in a way younger students would understand and reflected the intended categories; “if I were still in year 11, I even might have got them right” (Expert B).

One of the reviewers raised concerns that the themes focused too much on the practices of scientists “they are all very much about the ‘internalist’ activities of professional scientists” (Expert B). This had been an aspect of the items that the focus group had recommended be made more made explicit. The reviewer’s comment that the items seemed focused on professional science was considered by the researcher to be evidence that the items were capturing the version of science the study proper was set out to probe.

8.3. Descriptive Statistics

Each tenet subscale was analyzed using PASW 18 software to examine reliability and descriptive statistics of each item and subscale. The results were used to guide the factor analysis and interviews of the study proper.

8.3.1. Tentative NOS concepts

While minimal changes had been made to the tentative NOS items the Cronbach’s alpha for the tenet subscale dropped to .52. The alpha was not significantly improved by the deletion of any of the items (see Table 8.1a). The item-total correlations for items three, five and seven dropped from the first pilot study with item seven being the most notable dropping from .59 to .03. While in Pilot Study One item seven had elicited a strong neutral response, in Pilot Study Two it elicited a strong informed response (77%). As the item had not been altered the change was attributed to a difference in sample groups.

Table 8.1a

Item statistics for revised tentative items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Tent1	.40	.40
Tent2	.21	.49
Tent3	.36	.42
Tent4	.33	.45
Tent5	.34	.44
Tent6	.10	.53
Tent7	.03	.56

Item six had a notably high kurtosis value (see Table 8.1b) .This was attributed to a single outlier response but as removing the item did not significantly alter the alpha value or any other data it was not investigated further.

Table 8.1b

Descriptive statistics for revised tentative items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Tent1	8	1	9	5.45	2.14	-.52	-.21
Tent2	4	5	9	7.23	1.13	.09	-.43
Tent3	8	1	9	5.72	2.17	-.03	-.85
Tent4	6	1	7	4.23	1.49	-.09	-.39
Tent5	6	3	9	5.79	1.52	.18	-.65
Tent6	7	1	8	6.09	1.25	-1.43	4.54
Tent7	7	2	9	6.34	1.58	-.04	.25

8.3.2. Law and theory NOS concepts

The Cronbach’s alpha for the revised law and theory items remained unacceptable (.15) indicating that the items were weakly correlated (see Table 8.2a). As with Pilot Study One, when the informed and naïve items were analyzed separately the alphas improved to .48 and .47, respectively, but remained below the acceptable threshold. The item-total correlations did not indicate any clear correlations between the items, however the means between the informed and naïve items were again distinct, with most students selecting informed positions in response to the informed items and naïve positions in response to the naïve items (see Table 8.2b). The high kurtosis and skewness values for items one and two were identified as the consistent responses of one student to both items and so were not investigated further.

Table 8.2a

Item statistics for revised law and theory items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Law1	-.10	.23
Law2	-.06	.20
Law3	.12	.10
Law4	.10	.10
Law5	-.08	.23
Law6	.16	.04
Law7	.07	.12
Law8	.24	-.01

Table 8.2b

Descriptive statistics for revised law and theory items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Law1	7	2	9	6.72	1.41	-.70	1.72
Law2	7	2	9	6.45	1.25	-1.00	2.57
Law3	5	4	9	6.96	1.18	-.25	.03
Law4	6	3	9	6.38	1.42	-.34	.06
Law5	6	1	7	4.04	1.56	-.22	-.71
Law6	8	1	9	4.83	1.79	.32	-.26
Law7	7	1	8	3.51	1.93	.36	-.49
Law8	7	0	7	3.83	1.46	-.17	.32

8.3.3. Social NOS concepts

The Cronbach's alpha for the revised social items was an acceptable .81 which improved to .86 when item six was deleted. The item-total correlations showed strong correlations between all the items except items two and six. A significant proportion of students continued to select the neutral category in response to these items but this was consistent with both the focus group comments and the class discussion. As such the responses were attributed to the students' beliefs about social NOS concepts rather than uncertainty about interpretation.

Table 8.3a

Item statistics for revised social influence items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Soc1	.72	.76
Soc2	.18	.83
Soc3	.71	.76
Soc4	.75	.75
Soc5	.55	.78
Soc6	-.10	.86
Soc7	.57	.78
Soc8	.79	.74

Table 8.3b

Descriptive statistics for revised social influence items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Soc1	8	1	9	5.64	1.72	-.84	.76
Soc2	6	3	9	6.51	1.38	-.23	-.09
Soc3	8	1	9	5.72	1.79	-.32	.54
Soc4	7	2	9	5.66	1.63	.30	-.15
Soc5	8	1	9	4.85	1.77	-.28	-.17
Soc6	7	1	8	5.51	1.53	-.74	.62
Soc7	8	1	9	5.13	1.84	-.55	-.07
Soc8	8	1	9	5.38	2.16	-.26	-.45

8.3.4. Scientific Method NOS concepts

Following the significant changes made by the focus group to the scientific method items the Cronbach's alpha dropped to .05 which indicated weak correlations between the altered items. The alpha was not improved when any item was removed (see Table 8.4a). The descriptive statistics for the items indicated that students responded to the first three items in mostly informed ways while over 32% of the students opted for the neutral response for the last three items. While the results for the unaltered items in pilot study one had been acceptable the focus group had raised numerous concerns with these items. As no issues had been raised about the comprehensibility of the items, the scientific method subscale was identified as a specific aspect to discuss with the students in the later interviews.

Table 8.4a

Item statistics for revised scientific method items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Meth1	.09	-.05
Meth2	-.05	.12
Meth3	.11	-.03
Meth4	.03	.03
Meth5	.01	.05
Meth6	-.05	.12

Table 8.4b

Descriptive statistics for revised scientific method items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Meth1	6	3	9	5.28	1.53	.08	-.65
Meth2	5	4	9	6.60	1.53	.15	-.97
Meth3	4	5	9	6.64	1.09	.26	-.24
Meth4	7	2	9	5.70	1.40	.11	.70
Meth5	8	1	9	4.28	1.44	.26	1.66
Meth6	8	1	9	5.28	1.62	-.15	.91

8.3.5. Empirical evidence NOS concepts

The changes to the empirical evidence statements based on Pilot study one raised the Cronbach's alpha to .40 which increased to a near acceptable .65 when item one was deleted (see Table 8.5a). The item-total correlations of item one indicated it was again weakly correlated to the other items despite the wording change. While the change did not improve the items correlation to the subscale it was retained and the issue of how students interpreted this item was carried over to the interview stage of the study proper. The changes to the other items did raise their item-total correlations indicating they had improved correlations. The descriptive statistics for the remaining items were relatively consistent (see Table 8.5b) though both items four and six had a high percentage of students select the neutral option.

Table 8.5a

Item statistics for revised empirical evidence items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Emp1	-.24	.65
Emp2	.35	.29
Emp3	.21	.34
Emp4	.31	.26
Emp5	.45	.17
Emp6	.34	.27

Table 8.5b

Descriptive statistics for revised empirical evidence items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Emp1	8	1	9	4.40	2.01	-.01	-.61
Emp2	5	4	9	6.57	1.16	-.06	.22
Emp3	7	2	9	6.70	1.59	-.92	1.05
Emp4	7	2	9	5.64	1.81	-.07	-.58
Emp5	6	3	9	7.15	1.64	-.74	-.25
Emp6	5	4	9	6.30	1.40	.39	-.85

8.4. Summary

The purpose of the pilot studies was to test the interpretability of questionnaire items with year 11 students prior to their use as a screening tool for the main study. The results from the questionnaire data from Pilot study one provided insights into issues regarding both items and tenet subscales, and students in the focus group provided feedback that was used to modify problematic statements. The students in Pilot study two did not identify any further items as being confusing, but like the students in the focus group they struggled with the terms 'law' and 'theory' and were not sure if social influences affected science. The expert reviewers judged the items to be consistent with the NOS tenet subscales and regarded them as appropriate for the age group to be investigated in the main study.

The results from the pilot studies raised five unexpected questions about the NOS tenet subscales. First, with the tentative NOS subscale, why did students view scientific explanations as both changeable and absolute? For example, 57% of students in Pilot study two agreed that science finds out the absolute truth (i.e., item 4), whereas 93% of the students agreed that scientific explanations can change (i.e., item 2). This was unexpected because these beliefs appear to be mutually incompatible.

Second, why were students responding to the items in the law and theory subscale with such a clear split in responses? For example, over 75% of the responses to the informed items were informed, whereas less than 15% of the responses to the naive items five, seven and eight were informed. This was unexpected because the items appear to be probing two distinct constructs based on whether the item is written from an informed perspective or a naive perspective.

The third question pertained to two items on the social NOS subscale. Despite the fact that students did not raise any questions about items two and six, both of these items were weakly correlated with the remaining item on the subscale. Items two and six had no inter-item correlation above .3 (see Table 8.6a). Students raised questions about items on other subscales that showed weak correlations. Why did students not raise issues about these items?

Table 8.6a

Inter- items correlations for revised social influence items

	Soc1	Soc2	Soc3	Soc4	Soc5	Soc6	Soc7	Soc8
Soc1	1.00							
Soc2	.22	1.00						
Soc3	.61	.16	1.00					
Soc4	.63	.26	.65	1.00				
Soc5	.56	.26	.51	.44	1.00			
Soc6	-.09	-.28	.02	-.02	-.14	1.00		
Soc7	.47	.05	.39	.52	.32	.05	1.00	
Soc8	.68	.17	.69	.70	.51	-.09	.66	1.00

The fourth question pertained to the scientific method items. Why did the inter-item correlation among these items become weaker when changes were made to the wording of these items following Pilot study one? In Pilot study one, the alpha level was nearly acceptable (.69), but after revisions, the correlations between the items weakened (see Table 8.6b) and resulted in an unacceptable alpha (.03).

Table 8.6b

Inter- items correlations for revised scientific method items

	Meth1	Meth2	Meth3	Meth4	Meth5	Meth6
Meth1	1.00					
Meth2	.05	1.00				
Meth3	.06	.16	1.00			
Meth4	.23	-.15	.11	1.00		
Meth5	.02	-.13	-.07	.01	1.00	
Meth6	-.13	-.02	-.02	-.10	.16	1.00

Finally, why did two items on the empirical evidence subscale (i.e., items four and six) elicit neutral responses? For example over 34% of the responses to the two items were neutral compared to less than 15% of the responses to items two, three and five. This was unexpected because both items appeared to be consistent with other items in the tenet subscale.

While the subscale items were consistent with expert opinions of NOS, the weak correlations between some of the items and the student comments indicated that the items may not have been probing the intended constructs. This particular issue had been raised by one of the reviewers who pointed out that "although we assume sophisticated reasoning underpins [the items], in fact research shows that it can be impossible to tell the difference (in a survey) between a very naive anything-goes relativism and a nuanced, contextualized epistemologically sophisticated response" (Expert A).

The assumption at the outset of the study had been that knowledge of NOS concepts would dictate student responses, such that those with more knowledge of NOS concepts would answer the items differently and score higher than those with less understanding of NOS. The inconsistency in responses to some of the subscale items suggested that items were probing alternative constructs. While Cronbach's alpha can give an indication of reliability, it does not detect the dimensionality of items; it only correlates the high scores of one item with high scores of the others items in the subscale (Streiner, 2003). In order to explore possible alternative construct structures a larger sample was needed to conduct the appropriate factor analysis (Raykov & Marcoulides, 2011).

While items could be removed from the questionnaire on the basis that they are not probing the expected constructs, this is not a recommended practice because it can capitalize on chance events; reflecting a statistical artefact rather than a substantive issue (Raykov & Marcoulides, 2011). An example of this is the Pilot study two data for tentative item seven. The removal of an item needs to be based on a substantive reason, which cannot come from the limited data collected in the pilot studies. While students in both pilot studies indicated that they could comprehend the items, and the reviewers believed the revised items were appropriate, as stated above, questionnaire items may not distinguish between sophisticated reasoning and naive relativism. While students may be comfortable responding to the items, it is not clear whether the items were measuring NOS beliefs about each subscale or some other construct.

To investigate students' understanding of the items and of NOS in general, the study proper focused on two sources of data. The first was to explore possible alternative factor solutions in order to identify which items loaded to which constructs. Such an analysis required a large sample size, and as part of the study proper, four schools agreed to take part in the questionnaire phase of the main study. With the larger sample size, an exploratory factor analysis could be performed to identify which factor solutions best modelled the response data. These could then be tested with confirmatory factor analysis on a second data set to establish how robust the solutions were.

The second source of data is student interviews, in which they discussed their understanding of NOS and what they understood about specific questionnaire items. In phase two of the study proper, the questionnaire data were used to identify students for interviews. Students who provided different ranges of responses to the questionnaire were purposively sampled for interviews. The questions that emerged from the pilot studies along with the alternative factor solutions were used to shape and direct the interviews. Combining the questionnaire data with the interview responses allowed substantive reasons to be identified that could account for the constructs students used to answer the questionnaire items. These justified which items needed to be excluded and provided an overall description of what year 11 students understand about NOS.

The pilot studies addressed comprehension issues using the students' voices. The changes were reviewed by educators with expertise in NOS who confirmed that the revised items did still reflect valid NOS statements. The pilot studies had also unearthed unexpected issues that began to give insights into the understanding year 11 students had about NOS. The study proper, which included a larger sample size and individual semi-structured student interviews, was used to address these emerging questions in more depth and to address the research questions set out at the start of the study;

- What NOS concepts do New Zealand secondary students hold by their final year of compulsory science education?
- How do these concepts compare to core informed educational NOS concepts?
- What factors do students identify as influencing their understanding of NOS concepts?
- How do these influences interact to form the students' overall belief about NOS?

CHAPTER 9 – PHASE ONE: QUANTITATIVE STUDY

Introduction

The study proper began in April 2011 with the administration of the questionnaire to 532 participants. Following the statistical analyses, interviews were conducted with selected students. The following chapters describe the two phases of the mixed method approach used in this study. The methodology of phase one, the quantitative stage, is described in chapter nine and the statistical analyses and model fit data are examined in chapter 10. The methodology of phase two, the quantitative stage, is described in chapter 11 and the coding and analysis of the interview data are examined in chapter 12.

The purpose of the first phase of the study was to use the questionnaires data to identify potential groups of participants with similar response patterns. The researcher used descriptive statistics and EFA and CFA techniques to compare expected response patterns with those generated by the students. The methodology outlined in chapter nine revealed discrepancies between the expected factor structure and the apparent response structure which was explored further with the students during the interview phase of the study.

Method

9.1. Participants

The study included 532 year 11 students (244 female, 286 male, 2 gender not stated, median age 15) from four co-educational schools in the lower North Island of New Zealand. After screening, 30 participants were removed due to incomplete questionnaires or withdrawal of consent to leave a final sample size of 502 students (see section 9.4). At College One (*n=64*, decile 9) and College Two (*n=52*, decile 2) year 11 science was taught as an optional subject, a recent change to the New Zealand curriculum. At College Three (*n=206*, decile 8) and College Four (*n=180*, decile10) science was compulsory for all students; but at the latter a new school wide year 11 NOS unit had been completed just prior to the study.

9.2. Materials

Questionnaire

The final version of the NOS questionnaire contained 35 randomly ordered informed and naïve items intended to probe the five NOS subscales (see Appendix C for questionnaire and Tables 9.1a to 9.1e for listing of items by tenet). The questionnaire was modified to include space for the students' names, age and a space was left blank to add an identification number that would be used during the data entry and analysis stages. A research assistant added an identification number to the papers prior to data entry and maintained the master list of names and identification numbers. The identification number was then the only identifying reference visible to the researcher during the quantitative data analysis phase of the study. When the researcher selected participants for the interviews based on their NOS tenet subscale scores, the research assistant provided the names of the students selected in a randomized order. This step reduced the effect of interviewer bias that may have been caused by the researcher forming opinions about the students' NOS beliefs based on their subscale scores prior to the interviews taking place in phase two of the study.

Participants responded to each item on a nine-point Likert-scale (1 = strongly agree to 9 = strongly disagree). Seventeen items were meant to reflect informed beliefs, and 18 items were meant to reflect naïve beliefs. After the researcher entered the data into the data file, the 17 informed statements were reverse coded such that responses reflecting informed beliefs received a higher score (e.g., strongly agreeing with tentative NOS item "Science can never determine absolute truth" was scored as a 9), whereas responses reflecting naive beliefs received a lower score (e.g., strongly disagreeing with the law and theory item "If a scientific theory is proven right it becomes a scientific law" was scored as a 1). The data for the 18 naive statements were not reverse coded. A score over five indicated an informed belief about the NOS statement presented, while a score under five indicated a naïve belief about the statement. A score of five indicated that the student had not taken either position with regards to the statement. The summed responses for each subscale, following reverse coding, were: tentative items 7 to 63, law and theory items 8 to 72, social items 8 to 72, scientific method items 6 to 54, and empirical evidence items 6 to 54.

Table 9.1a
Tentative NOS items

Item	Statement
Tent1	Science can never determine absolute truth.
Tent2	New evidence can change scientific explanations.
Tent3	No scientific explanation can be proven to be absolutely true.
Tent4	The study of science finds out the absolute truth about the world around us.
Tent5	Established scientific explanations are absolutely correct.
Tent6	Established scientific explanations never change.
Tent7	Science books contain absolutely true explanations.

Table 9.1b
Law and Theory NOS items

Item	Statement
Law1	Scientific theories are created to explain patterns in the world around us.
Law2	Scientific laws are created to describe observations made about the world around us.
Law3	New evidence can change scientific laws.
Law4	Scientific laws are temporary and change with new discoveries.
Law5	If a scientific theory is proven right it becomes a scientific law.
Law6	Scientific laws are fixed and work everywhere.
Law7	Scientific laws exist in nature before we discover them.
Law8	Scientific theories become scientific laws when enough evidence is collected.

Table 9.1c
Social NOS items

Item	Statement
Soc1	Personal beliefs influence scientific observations.
Soc2	Scientific data can be interpreted in many different ways.
Soc3	Values and beliefs influence scientific research.
Soc4	Experience and beliefs affect the interpretation of scientific data.
Soc5	Scientific research is not affected by personal beliefs.
Soc6	Past explanations do not affect new scientific explanations.
Soc7	Personal values and goals do not influence the way scientific evidence is interpreted.
Soc8	Personal beliefs do not influence scientific explanations.

Table 9.1d

Scientific Method NOS items

Item	Statement
Meth1	Professional scientific experiments can never be measured exactly.
Meth2	There is no single scientific method.
Meth3	Many different scientific methods are used to solve scientific questions.
Meth4	Professional scientific experiments produce exact results.
Meth5	The scientific method refers to the steps all scientific experiments follow.
Meth6	There is one scientific method that is always used in the same way.

Table 9.1e

Empirical NOS items

Item	Statement
Emp1	Scientific evidence only includes data from the world around us.
Emp2	Scientific explanations are created by interpreting evidence.
Emp3	Scientific explanations are based upon evidence.
Emp4	Scientific explanations are created before data is collected.
Emp5	Scientific explanations do not need evidence to be accepted.
Emp6	Scientific evidence does not need to be interpreted.

9.3. Procedure

Questionnaire administration

The questionnaire was administered during the students' regular science lessons. Prior to distributing the questionnaire, the researcher explained to the students that the purpose of the study was to understand students' beliefs about how science worked. The researcher also indicated that some of them would be later asked to participate in a voluntary semi-structured interview. The students were each given a study information sheet and a consent form (see Appendix E) to sign. A withdrawal of consent form was given to the students to take home in case parents did not wish to give consent (see Appendix G) as per the ethics board recommendations. The researcher read through each form with the students to ensure they all understood the purpose of the study and their rights as research participants. The researcher informed all the students that participation in the study was entirely voluntary and that they could withdraw that consent at any point during the data collection stage.

The students were asked to respond to the questionnaire items based on their own beliefs about science and were informed that there were no right or wrong answers. The students were asked to annotate with question marks or comments any items that they found confusing. They were given 30 minutes to complete the questionnaire.

9.4. Data Analysis

The students' questionnaires were scanned for annotations and relevant details were recorded as part of the questionnaire data. The researcher screened the questionnaire sheets and consent forms and 30 papers were excluded from the final study due to the following reasons: (a) the consent forms were not fully completed (n = 3), (b) the participant withdrew consent after completing the questionnaire (n = 2), (c) the participant did not complete the questionnaire (n = 18), and (d) the participant answered the questionnaire with a random response pattern (e.g., all statements were marked with a one) (n = 7).

The remaining 502 questionnaires were each given an identification code by a research assistant, who then entered the data into an Excel spreadsheet. Spot checks were completed to ensure the fidelity of the data transfer before the informed items were reverse coded. The specified items were reverse coded to ensure a high score was indicative of an informed response and a low score was indicative of a naïve response for all 35 items.

The researcher used PASW 18 software to examine the reliability (i.e., Cronbach's alpha), corrected item-total correlations, and descriptive statistics for the items from each NOS tenet subscale. Cronbach's alphas were used to measure the internal consistency of items within each subscale and were compared to the pilot study data. Alphas above .7 indicated an acceptable level of consistency across the subscale items. Item-total correlations and the descriptive statistics were used to identify items that had similar responses in a given subscale from those which appeared to be answered using a different construct. This information was later used to support substantive interpretations of alternative factor solutions.

To examine the fit of the items to the expected NOS tenet subscales, the researcher used AMOS 18 software to conduct a confirmatory factor analysis (CFA) on the NOS subscale model (see Figure 9.1). The loadings of the items to the expected subscale constructs were examined along with the goodness of fit data for the model. The subscale factors were considered acceptable if three or more items loaded above .5 on the factor and all other expected items loaded above the minimum threshold of .3 (Costello & Osborne, 2005). While Chi-square (χ^2) is the most commonly reported goodness of fit statistic reported for factor analysis, it is known to be sensitive to sample size (e.g., larger samples mean larger χ^2 values) and to be sensitive to the number of constraints imposed on the model (e.g., more constraints means a larger χ^2 values, (Hu & Bentler, 1995). It is recommended that for large, highly constrained data sets the χ^2 values of possible models be used as relative measures of fit between the models, and that a range of additional fit indices should be used to help select the most appropriate model (Hoyle & Panter, 1995; Jackson, Gillaspy, & Purc-Stephenson, 2009).

While AMOS 18 reports multiple different fit measures, the normed chi-square (χ^2/df), root mean square error of approximation (RMSEA), Tucker-Lewis index (TLI) and comparative fit index (CFI), were selected as the most useful measures based on the recommendations of Hu and Bentler (1995) and Raykov and Marcoulides (2011). While each of these measures are also affected by issues of sample size and model complexity, they represent a range of recommended fit measures that can be used holistically to assess the validity of the models being tested. The acceptable threshold values used for the fit indices in this study were; χ^2 values with $p>.05$, (χ^2/df) > 2, RMSEA <.08, TLI and CFI >.9 (Hooper, Coughlan, & Mullen, 2008; Hu & Bentler, 1995, 1999)

To explore possible alternative factor solutions, PASW18 was used to randomly split the sample into two groups (*n=251*). One subset was used to conduct an exploratory factor analysis (EFA) to identify potential factor solutions using the PASW 18 factor analysis function. The resulting factor solutions were judged on the following selection criteria:

- The number of factors extracted compared to the number of factors above the elbow of the associated scree plot,
- The number of factors extracted compared to the number of factors with eigenvalues greater than 1.0,
- The number of extracted factors that contained three or more items with loadings above .5,

- The number of items in the solution with cross loadings of more than .3 to multiple factors,
- The number of items in the solution failing to load above .3 to any factor

(Costello & Osborne, 2005; Raykov & Marcoulides, 2011).

AMOS 18 was then used to create models of the data-driven factor solutions that best met these criteria and a CFA was conducted using the second half of the data (*n=251*). The factor loadings and goodness of fit data (i.e., χ^2, χ^2/df, RMSEA, TLI and CFI) for each of the selected data driven models was examined to identify if they were an improvement on the fit indices of the NOS tenet subscale model. The factor structures of the data driven models with improved fits were examined and potential substantive descriptions, based on the items included in each factor, were identified. Cronbach's alpha for these new factors were calculated and factor items that lowered the alpha were identified and discussed in the interviews. The constructs were later analyzed alongside the interview data to identify substantive reasons to justify the number of factors retained and the choice of construct labels. Items that failed to load to any factor above the .3 threshold were identified and discussed with the participants during the interviews.

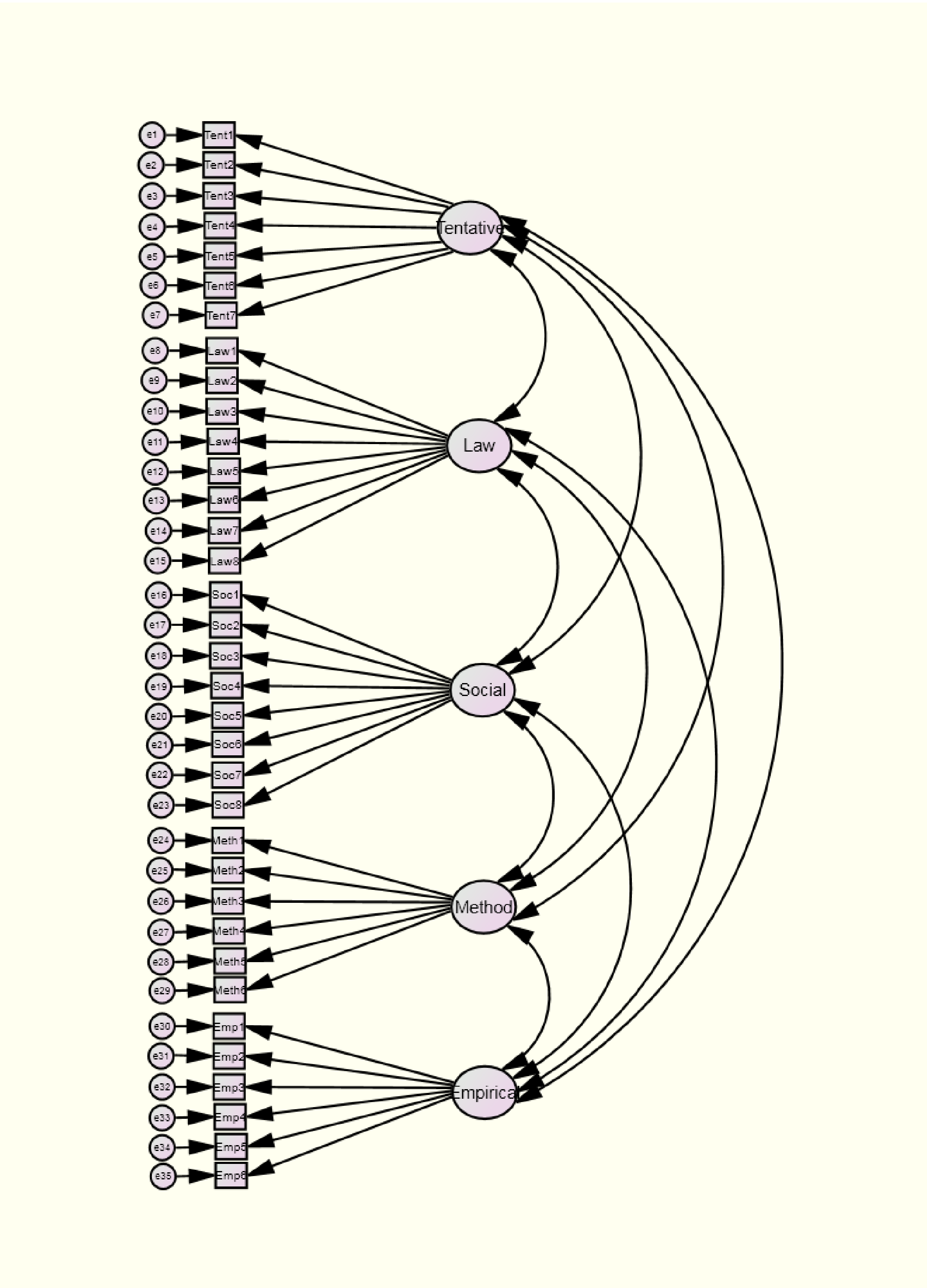

Figure 9.1. AMOS 18 model of theoretical NOS tenet subscale constructs

CHAPTER 10 – QUESTIONNAIRE RESULTS

10.1. Annotations

Only fifteen (5 male, 10 female) of the 532 students annotated their sheets. Four of the students commented on the end of questionnaire statement ‘do you think the science you are learning will be useful to you in later life?’ One of the students noted it would be “for a job” while one noted “some” of the science was. The other two noted “not really” and “not at the moment”. One student also responded to the statement ‘do you intend to continue to take science classes?’ with the annotation “I want to but find it difficult”.

One of the male students made annotations to seven of the items. Beside law item six (‘scientific laws are fixed and work everywhere’), scientific item four (‘professional scientific explanations produce exact results’) and tentative item seven (‘scientific books contain absolutely true explanations’) he wrote “they should”. Consistent with this, beside tentative item three (no scientific explanation can be proven to be absolutely true), he wrote “so far” indicating he believed it was possible. He also strongly agreed with social item seven (personal values do not influence the way scientific evidence is interpreted) but beside it wrote “unless?” however he gave no further indication of what this meant. He also question marked scientific item six (‘there is one scientific method that is always used in the same way’) and beside empirical item one (scientific evidence only includes data from the world around us) wrote “our planet? Is that a figurative speech?”

Like this student two other male students also annotated empirical item one writing “what do you class as that” and “everywhere?” beside it. One female student also wrote “space?” beside the item indicating that the term ‘world around us’ was generating the same issues ‘natural world’ had. One other male student also annotated law item nine, noting that laws were fixed “only on this planet” while one female student also wrote “not sure” beside the item. One female student also annotated scientific method item four, noting that the results would be exact “if repeated”.

One female student wrote beside tentative item two (‘new evidence can change scientific explanations’) “if it is relevant”. A female student wrote beside social item one (personal beliefs influence scientific observations’) “sometimes but shouldn’t”, while another wrote beside social item seven (‘personal beliefs do not influence scientific explanations') "personal beliefs should not affect, but do." Finally one male student annotated tentative item one ('the study of science finds out the absolute truth about the world around us') changed his initially strongly disagreed to strongly agreed but beside the change he wrote "it can be challenged or changed".

10.2. Descriptive Statistics

Each tenet subscale was analyzed using PASW 18 software to examine the reliability and descriptive statistics of each item on the subscale. The results were used assess the normality of the data and to help with later interpretations of possible factor solutions. The results were also used to identify aberrant items that would be discussed in the interviews (see section 9.2 for items listed by tenet).

10.2.1. Tentative NOS concepts

The Cronbach's alpha for the tentative NOS items was a near acceptable .68 which was not substantially improved by the deletion of any of the items (see Table 10.1a). The corrected item-total correlations for all the items except item two were acceptable (above .3), but as deleting item two did not substantially affect the alpha, it was retained. While no changes had been made to item seven the weak correlation detected with it in Pilot study two did not reappear with the study proper indicating that the response may have been unique to that group of students.

Table 10.1a

Inter statistics for tentative NOS items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Tent1	.42	.64
Tent2	.16	.70
Tent3	.36	.66
Tent4	.40	.65
Tent5	.56	.60
Tent6	.37	.65
Tent7	.48	.62

Item two had a higher mean than the other tentative items (see Table 10.1b) with 91% of students agreeing with the statement “New evidence can change scientific explanations”. Only item four elicited a generally naive response with 53% of students agreeing that “the study of science finds out the absolute truth about the natural world”. This dichotomy mirrored the results seen in the Pilot studies (see section 8.4) and suggested that the items were not measuring the same underlying, predetermined factor.

Table 10.1b

Descriptive statistics for tentative NOS items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Tent1	8	1	9	5.66	2.21	-.33	-.69
Tent2	8	1	9	7.51	1.37	-.98	1.52
Tent3	8	1	9	5.99	2.09	-.35	-.48
Tent4	8	1	9	4.51	2.11	.31	-.68
Tent5	8	1	9	5.97	1.76	-.22	-.36
Tent6	8	1	9	6.70	1.67	-.80	.83
Tent7	8	1	9	6.10	1.90	-.40	-.29

10.2.2. Law and theory NOS concepts

The Cronbach’s alpha for the eight law and theory items was an unacceptable .09, which indicated only weak correlations between the items (see Table 10.2a). The alpha was not improved by deleting any of the items. Like the data from both pilot studies, the means for the first four informed items were notably different than the means for the naive items (see Table 10.2b).

When the statements were separated into an informed and a naive subscale, the informed items alpha was .60 while the naïve items alpha was .43. The results were still below the acceptable threshold of .7 indicating that the separated subscale items did not share sufficiently strong correlations.

The means of the eight items highlighted the significant difference between the informed and naive item responses. Over 75% of the responses for the first four items were informed, whereas less than 6% of the responses were naive. By comparison, over 50% of the responses to items five, seven and eight were naive. Item seven elicited the strongest naive response with over 74% of the students agreeing that ‘Scientific laws exist in nature before we discover them". This response was puzzling as item six, which stated "Scientific laws are fixed and work everywhere", only elicited a naive response from 28% of the students despite the two items being derived from the same NOS misconception.

Table 10.2a

Item statistics for law and theory items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Law1	-.03	.11
Law2	-.01	.10
Law3	.14	-.01
Law4	.15	-.03
Law5	.11	.00
Law6	.17	-.07
Law7	-.22	.26
Law8	-.05	.13

As the results were the same as the pilot study data and suggested alternative constructs to those anticipated were in action, the researcher included the question "What do you understand by the term scientific law" and "What do you understand by the term scientific theory" into the semi-structured interview protocol.

Table 10.2b

Descriptive statistics for law and theory items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Law1	8	1	9	6.73	1.48	-.45	.47
Law2	8	1	9	6.55	1.44	-.46	.80
Law3	8	1	9	7.09	1.52	-.80	.87
Law4	8	1	9	6.75	1.63	-.54	.30
Law5	8	1	9	4.40	1.74	.25	-.25
Law6	8	1	9	5.41	1.93	-.13	-.46
Law7	8	1	9	3.07	1.73	.48	-.42
Law8	8	1	9	4.02	1.57	.31	.26

10.2.3. Social influence NOS concepts

The Cronbach’s alpha for the social items was an acceptable .76 which improved slightly to .78 when item six was deleted (see Table 10.3a). Only items two and six had weak item–total correlations indicating the responses to those items were not related to the other items in the subscale. Both items elicited informed responses from the students, 55% for item six and 77% for item two.

The remaining social items elicited a mixture of responses which resulted in item means that are close to the neutral value of five (see table 10.3b). While over 22% of the responses to the six correlated items were neutral, relatively similar percentages of students responded to the items with informed and naive responses (i.e., for item eight, 42% of students selected an informed response compared 33% selected a naive response and 25% who selected the neutral category). The high corrected item-total correlations for these six items indicate that most students were responding to them in a consistent manner. Item two and six by comparison appear to be influenced by some other construct.

As the students tended to give neutral responses to these items, the researcher included the question “Are scientists affected by their beliefs” into the semi-structured interview protocol to begin to probe the students’ understanding of the social interactions and influences involved in science.

Table 10.3a

Item statistics for social items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Soc1	.54	.71
Soc2	.20	.77
Soc3	.59	.70
Soc4	.60	.70
Soc5	.49	.72
Soc6	.18	.78
Soc7	.52	.72
Soc8	.50	.72

Table 10.3b

Descriptive statistics for social items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Soc1	8	1	9	5.05	1.92	-.33	-.45
Soc2	8	1	9	6.65	1.43	-.55	.85
Soc3	8	1	9	5.32	1.92	-.34	-.27
Soc4	8	1	9	5.46	1.75	-.46	-.02
Soc5	8	1	9	4.48	2.08	.19	-.64
Soc6	8	1	9	5.76	1.91	-.32	-.55
Soc7	8	1	9	5.18	1.90	-.16	-.28
Soc8	8	1	9	5.14	1.99	-.23	-.46

10.2.4. Scientific method NOS concepts

The Cronbach's alpha for the scientific method NOS items was an unacceptable .38, which was not improved by the deletion of any items (see Table 10.4a). All the items had item-total correlation below .3 indicating that they were weakly correlated.

Table 10.4a

Item statistics for scientific method items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Meth1	.16	.36
Meth2	.16	.36
Meth3	.12	.38
Meth4	.28	.27
Meth5	.11	.39
Meth6	.26	.29

Items two, three, five and six made specific references to the scientific method yet they elicited a range of responses (see Table 10.4b). Eighty-five percent of students selected an informed response for item three "Many different scientific methods are used to solve scientific questions" ($M = 6.85$) while only 20% of students selected an informed response for item five "The scientific method refers to the steps all scientific experiments follow” (*M = 4.66*). In response to the inconsistency of the responses to items that used the term ‘scientific method’ the researcher included the question “What do you understand by the term scientific method” into the semi-structured interview protocol. The questionnaire responses indicated that students did not understand this term in the way that was expected.

Table 10.4b

Descriptive statistics for scientific method items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Meth1	8	1	9	5.28	1.91	-.12	-.41
Meth2	8	1	9	6.69	1.90	-.66	.15
Meth3	8	1	9	6.85	1.26	-.52	1.15
Meth4	8	1	9	5.59	1.74	-.30	-.38
Meth5	8	1	9	4.66	1.60	.01	.35
Meth6	8	1	9	5.84	1.72	.01	-.25

10.2.5. Empirical evidence NOS concepts

The Cronbach’s alpha for the empirical evidence items was an unacceptable .40 but this improved to .59 when item one was excluded. Item one was weakly correlated with the other items (see Table 10.5a) indicating that the changes made to the item in the pilot studies had not worked. The difficulties associated with the wording and interpretations of the item were specifically addressed in subsequent interviews during the qualitative phase.

Table 10.5a

Item statistics for empirical evidence items

Item	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Emp1	-.16	.56
Emp2	.35	.26
Emp3	.28	.29
Emp4	.20	.32
Emp5	.29	.27
Emp6	.25	.30

Over 65% of the responses to items two, three, five and six were informed and resulted in the items having high means (see Table 10.5b). Item four elicited a relatively high percentage of neutral (32%) and naive (22%) responses. These responses contrasted with similar items and indicated that the same dichotomy seen in the tentative item responses may be affecting the empirical evidence items.

Table 10.5b

Descriptive statistics for pilot study empirical evidence items

Item	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Emp1	8	1	9	4.12	1.80	.23	-.04
Emp2	8	1	9	6.61	1.31	-.37	.86
Emp3	8	1	9	6.76	1.48	-.86	1.63
Emp4	8	1	9	5.64	1.84	-.18	-.35
Emp5	8	1	9	7.33	1.77	-.96	.32
Emp6	8	1	9	6.39	1.75	-.49	.10

10.3 Descriptive Statistics Summary

The Cronbach’s alpha values for the tentative items closely resembled the pilot trial data. Despite wording changes applied following the focus group discussions, the alpha value remained just below the threshold. Item two (‘new evidence can change scientific explanations’) continued to be an aberrant item with over 90% of students selecting an informed response to the statement. Based on the descriptive statistical data it appeared that item two was not interpreted by students as intended and may have probed a different underlying construct.

The law and theory items also closely mirrored the results from the pilot study even with student derived revisions to the wording of items seven and eight. The responses likely reflected the focus group observation that students were unfamiliar with the details of what law and theory meant. In the absence of explicit knowledge about the role and purpose of law and theory, alternative constructs were likely to have mediated the responses. These constructs were explored through the factor analysis.

The social items were the only group of items to have an alpha value above the .7 threshold. This was an improvement on the first pilot study data where the original fifth social NOS item had had a significant effect in lowering the alpha value. The replacement item was more consistent with the overall theme and allowed two aspects to come through in the trial data. First, items two and six both had higher means and a more informed leaning distribution than the other items. Second, while the means of the remaining items were close to the neutral position they had an even distribution either side indicating that the students involved in the study held a range of beliefs about the statements.

The Cronbach's alpha value for the scientific method pilot items had been close to the .7 threshold (.67 when item two was excluded). The changes made following the focus group significantly reduced that value. The simplification of the statements following the input of the focus group appeared to remove some of the uncertainty about the informed items but it did not appear to clarify the naïve items. While the focus group data was expected to improve the correlation of the items, in this case it appeared to reduce it. A deeper analysis of the potential conflicts of this group was done through the factor analysis.

Unlike the scientific method items, the empirical items did have a significantly improved Cronbach's alpha value following the help of the focus group. While the items still failed to meet the .7 threshold value needed to reflect a single construct they did have a comparatively strong value of .59 when item one was excluded. The remaining items also elicited strongly informed responses though both item four and six still had a number of students opting for a neutral position in relation to those specific statements.

The descriptive statistical data indicated that despite the theoretical framework used to design the questionnaire only the social NOS items appeared to probe an intended construct. Many of the other items had improved Cronbach's alpha values when examined as separate naive and informed groups of items. This observation suggested that alternative constructs could underlie the students' responses. While the pilot study had been too small to allow factor analysis to be used to explore other possible construct solutions, the larger number of participants in the full study meant that alternative factor structures could be examined to see if the items had been interpreted in an unexpected way. The pilot studies had helped identify wording and interpretation issues with the items. The analysis of the descriptive data now alerted the researcher that alternative constructs to the ones expected may have been guiding students' responses to the items and needed to be explored with the factor analysis.

10.4. Factor Analysis

Cronbach's alpha provide information about how reliably items vary in the same way but do not provide information about the dimensionality of the items (i.e., are varied responses governed by the same underlying construct?). This is a limitation of Cronbach's alpha usage; it measures the variance of items only in the same direction, not their relative variation (Raykov & Marcoulides, 2011). While the failure of the items to vary in the same way can be viewed as an indication that the items are not measuring the same construct, the pilot study data indicated that students considered their response to be consistent. The items used in the questionnaire had been grouped and coded according to informed expert beliefs about NOS, but the descriptive statistics indicated that the students had not responded to items assumed to measure the same construct/factor in a consistent way.

To examine what relationships existed between the items, factor analysis techniques were needed. Factor analysis allows the dimensionality of the items to be explored in order to identify if latent constructs inform the way students respond to items (Raykov & Marcoulides, 2011). As the study was based on the assumption that the items were measuring beliefs about the five NOS tenet subscale, this model needed to be tested. As this theoretically derived model existed and had been used to design the questionnaire it could be tested with CFA techniques using the data collected from the study and then it could be compared with other possible factor solutions generated through EFA techniques.

10.4.1. Confirmatory factor analysis

A CFA is used to determine if a predetermined factor model accurately captures the relationships of a measured data set (Raykov & Marcoulides, 2011). As the NOS questionnaire was designed with the assumption that students would respond to the items based on the expert-defined NOS tenet subscales, this provided a theoretical model against which to test the empirical data. The theoretical NOS concepts model (see Figure 10.1) restricted the items to specific latent variables (i.e., the tentative NOS concept items were only linked to the tentative NOS construct). The latent variables (i.e., the scientific method and empirical evidence constructs) were allowed to correlate as social science constructs were expected to be related and not wholly independent of each other (Costello & Osborne, 2005; Raykov & Marcoulides, 2011).

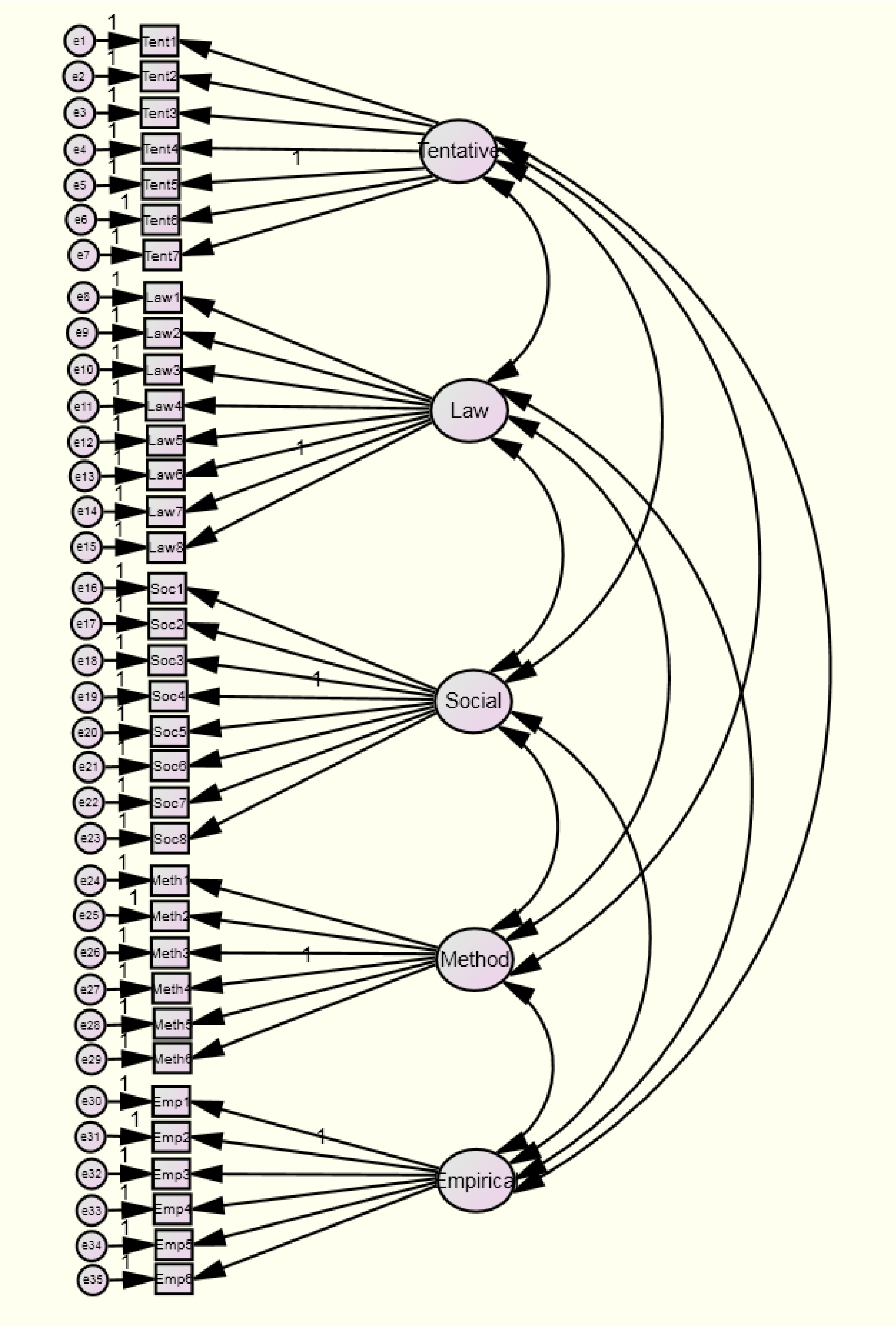

Figure 10.1. NOS tenet subscale model with scale indicators

Note: Items Tent5, Law2, Soc3, Meth4 and Emp2 were defined as the indicator items and had regression weights set to 1. All latent constructs were allowed to correlate.

The model was constructed using AMOS 18 software which, unlike PASW 18, allows the user to link items to specific latent variables and restricts other items from being associated with them (Cabrera-Nguyen, 2010). In order to define the model, one item from each subscale needed to be identified as the indicator item for the NOS tenet. As the indicator is the item with the strongest link to the specific latent variables (subscales), the items with the greatest absolute item-total correlation from the descriptive statistics were set as the initial indicator items. These items, (tentative item five (.57), law item seven (-.22), social item four (.61), method item four (.29) and empirical item two (.37) had their regression weights set to "one" to act as the scale by which all other regression weights for that subscale were measured.

The model was run with a maximum likelihood extraction, and the initial regression weight estimates were examined to identify if any of the items had loadings greater than one, which would indicate that more than 100% of the variation in the item responses was attributed to the construct. In the case of the law items, item two had a scaled weighting of 1.22 and so it was adjusted to be the indicator item for the law tenet subscale. For the social items, item three had a scaled weighting of 1.14 and so it was set to be the indicator item for the social tenet subscale. The model was redefined based on these data and run with the new indicators. The model was evaluated using the factor loadings data and the goodness of fit data (i.e., χ^2, χ^2/df, RMSEA, TLI and CFI) to establish the appropriateness of using the expert-defined latent variables to interpret students' beliefs about the NOS.

10.4.2. CFA of theoretical NOS concepts model

To ensure the empirical data was appropriate for factor analysis, the data set (N=502) was examined using PASW 18 software. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, which is used to evaluate the adequacy of the data for factor analysis, was .83 (above the recommended minimum value of .6) and the Bartlett's test of sphericity, a second common measure of sampling adequacy, was significant (χ^2 (N = 502) = 4414, $p < .05$). The diagonals of the anti-image correlation matrix were all above .5 and 26 of the 35 items had one or more correlations above .3. Collectively, these findings indicated that the questionnaire data was appropriate for use with factor analysis techniques (Raykov & Marcoulides, 2011).

Maximum likelihood was used as the extraction method as the sample data showed relatively normal distribution (Costello & Osborne, 2005). Factor loadings for all items associated with a construct should be above .32 for the model to be considered as consistent with the empirical data and at least three of the items for each factor should have strong loadings above .5 (Costello & Osborne, 2005). The factor loadings (see Table 10.6) indicated that the model failed to accurately match the empirical data. Nine of the thirty-five items failed to load above the .3 threshold, and only the tentative and social NOS tenet subscales had at least three items with loadings above .5. The law and theory NOS tenet subscale had seven items with absolute loadings greater than the .3 threshold, but the three naïve items were negatively loaded to the factor. The scientific method NOS tenet subscale items had only three items with loading above .3 and only item four (Meth4) loaded above .5. The empirical evidence items had four items that loaded above the threshold value but only two items loaded above .5.

Significant correlations were detected between the tentative and scientific method latent variables (.88), and between the law and theory and empirical evidence latent variables (.79). A correlation was also detected between the tentative and empirical evidence items (.31). The size of the correlations supports the conclusion that the items were not being primarily influenced by the expected latent variables; rather, they were instead informed by different constructs.

As described in section 9.4, multiple goodness of fit measures were assessed due to the large sample size and complexity of the model being tested. In this case, the goodness of fit data for all the reported measures were poor, χ^2 (550, N=502) = 2248, p <0.05, χ^2/df = 4.09, RMSEA = .08, TLI = .54, CFI = .57. The fit indices reported failed to meet the acceptable thresholds indicating that the latent variables and constraints used in the model did not reflect the underlying structure of the students' responses.

Although the tentative and social NOS latent variables showed evidence that they could be probing those specific NOS concepts, the loading structures, goodness of fit data and descriptive statistical data indicated that alternative constructs could better reflect the students' responses to these items. The theoretical NOS concepts model did not appear to model how year 11 students understood the items. To better understand what students believed about the relationship of the items and science in general, alternative factor solutions were explored.

Table 10.6a

AMOS 18 CFA loadings for theoretical NOS tenet model (N=502)

			Factor			
Items	Tentative	Law	Social	Method	Empirical	α
Tent1	.44	-	-	-	-	
Tent2	.23	-	-	-	-	
Tent3	.36	-	-	-	-	
Tent4	.47	-	-	-	-	
Tent5	.75	-	-	-	-	
Tent6	.56	-	-	-	-	
Tent7	.62	-	-	-	-	
						.68
Law1	-	.58	-	-	-	
Law2	-	.65	-	-	-	
Law3	-	.49	-	-	-	
Law4	-	.40	-	-	-	
Law5	-	-.33	-	-	-	
Law6	-	-.08	-	-	-	
Law7	-	-.44	-	-	-	
Law8	-	-.43	-	-	-	
						.09
Soc1	-	-	.69	-	-	
Soc2	-	-	.24	-	-	
Soc3	-	-	.75	-	-	
Soc4	-	-	.72	-	-	
Soc5	-	-	.55	-	-	
Soc6	-	-	.17	-	-	
Soc7	-	-	.54	-	-	
Soc8	-	-	.53	-	-	
						.76
Meth1	-	-		.31	-	
Meth2	-	-		.17	-	
Meth3	-	-		-.01	-	
Meth4	-	-		.66	-	
Meth5	-	-		.23	-	
Meth6	-	-		.36	-	
						.37
Emp1	-	-		-	-.10	
Emp2	-	-		-	.70	
Emp3	-	-		-	.54	
Emp4	-	-		-	.21	
Emp5	-	-		-	.36	
Emp6	-	-		-	.35	
						.40

Note: Only loading values to intended constructs are shown.

10.4.2.1. CFA of item deleted model

To identify items that could be deleted in the model, the correlation matrix of the data was examined and items that correlated with less than 20% of the other items in a tenet above .3 were eliminated from the model (Moss, 2008). A number of items also had correlations above .3 with items in other tenets suggesting they were probing other constructs and were also eliminated. This process eliminated eighteen items, including all of the scientific method and empirical evidence items and half of the law and theory items.

Multiple goodness of fit measures were assessed for the modified seventeen item model. The goodness of fit data remained poor across all the measures, χ^2 (112, N=502) = 700.112, $p < 0.05$, $\chi^2/df = 6.035$, RMSEA = .10, TLI = .66, CFI = .71. The fit indices failed to meet the acceptable thresholds and the modification indices indicated that many of the items would be better correlated with other items. The failure of the model despite expert reviews that indicated the items were appropriate gave further evidence that alternative factor structures needed to be explored.

Table 10.6b

AMOS 18 CFA loadings for 17 item modified NOS tenet model (N=502)

	Factor			
Items	Tentative	Law	Social	α
Tent1	.44	-	-	
Tent2	.23	-	-	
Tent3	.36	-	-	
Tent4	.47	-	-	
Tent5	.75	-	-	
Tent6	.56	-	-	
Tent7	.62	-	-	
				.68
Law1	-	.58	-	
Law2	-	.65	-	
Law3	-	.49	-	
Law4	-	.40	-	
				.60
Soc1	-	-	.69	
Soc3	-	-	.75	
Soc4	-	-	.72	
Soc5	-	-	.55	
Soc7	-	-	.54	
Soc8	-	-	.53	
				.80

10.4.3. Exploratory factor analysis

Exploratory factor analysis (EFA) is a widely used statistical technique that has few absolute guidelines governing its use in the social sciences (Costello & Osborne, 2005). The primary purpose of EFA is to explore the way in which data can be collected together; however, it is capable of producing an infinite number of possible factor solutions with no absolute measure of certainty. Because of this judgment, criteria need to be used to help identify useful interpretable solutions from those that are mathematically equivalent but uninterpretable.

In order to identify the most interpretable solutions, the criteria set out in section 9.4 were used. The eigenvalues, scree plot and loading structures of potential factor solutions were examined to identify those which could provide substantive explanations for the loading of items to constructs. In order to explore possible factor solutions, PASW 18 software was used to randomly-split the sample data into two groups. One set (*n=251*) was used in the EFA to explore possible factor solutions and the other set (*n=251*) was used to test models created from the factor solutions using CFA. For the EFA, maximum likelihood was used as the extraction method as the data was approximately normally distributed. Oblique rotation (promax) was also used as the latent variables were expected to be correlated (Costello & Osborne, 2005).

10.4.4. Exploration of factor solutions

The EFA data set was first examined to ensure that it was appropriate for use with factor analysis. The KMO measure of sampling adequacy for the sample was an acceptable .78 and the Bartlett's test of sphericity was significant (χ^2 (n = 251) = 2457, $p < .05$). The diagonals of the anti-image correlation matrix were all above .5 and 27 of the 35 items had one or more correlations above .3. Collectively, these calculations indicated that the sample data was appropriate for use with factor analysis techniques.

An initial EFA was conducted with the default setting of extracting all factors with eigenvalues above one. This analysis allowed the eigenvalue data (see Table 10.7) and scree plot data (see Figure 10.2) for the sample to be collected for use in identifying the most interpretable factor solutions. Ten factors had eigenvalues greater than one and cumulatively accounted for 59% of the variance. The scree plot elbow occurred at the fifth factor, though an additional drop was notable between the seventh and eighth factors.

The pattern matrix based on the factors with eigenvalues greater than one had little explanatory power (see Table 10.8). While four items failed to load, and one item had a cross loading above the .3 threshold, only one of the ten factors contained more than three items with loadings greater than .5. Five of the factors contained one item with a loading greater than .5 and three other factors contained two items each with loadings greater than .5. The fifth factor also contained only one item with a loading in excess of one. While the ten factor solutions is the most accurate representation of the data, it does not provide a 'clean' solution and so was not examined beyond noting that six of the social concept items formed the only factor that met the judgment criteria.

Table 10.7

Eigenvalues for EFA sample data

	Initial Eigenvalues		
Factor	Total	% of Variance	Cumulative %
1	4.87	13.91	13.91
2	4.38	12.09	26.42
3	2.61	7.46	33.87
4	1.96	5.60	39.47
5	1.33	3.79	43.27
6	1.29	3.67	46.94
7	1.19	3.41	50.35
8	1.10	3.15	53.50
9	1.09	3.12	56.62
10	1.02	2.91	59.54

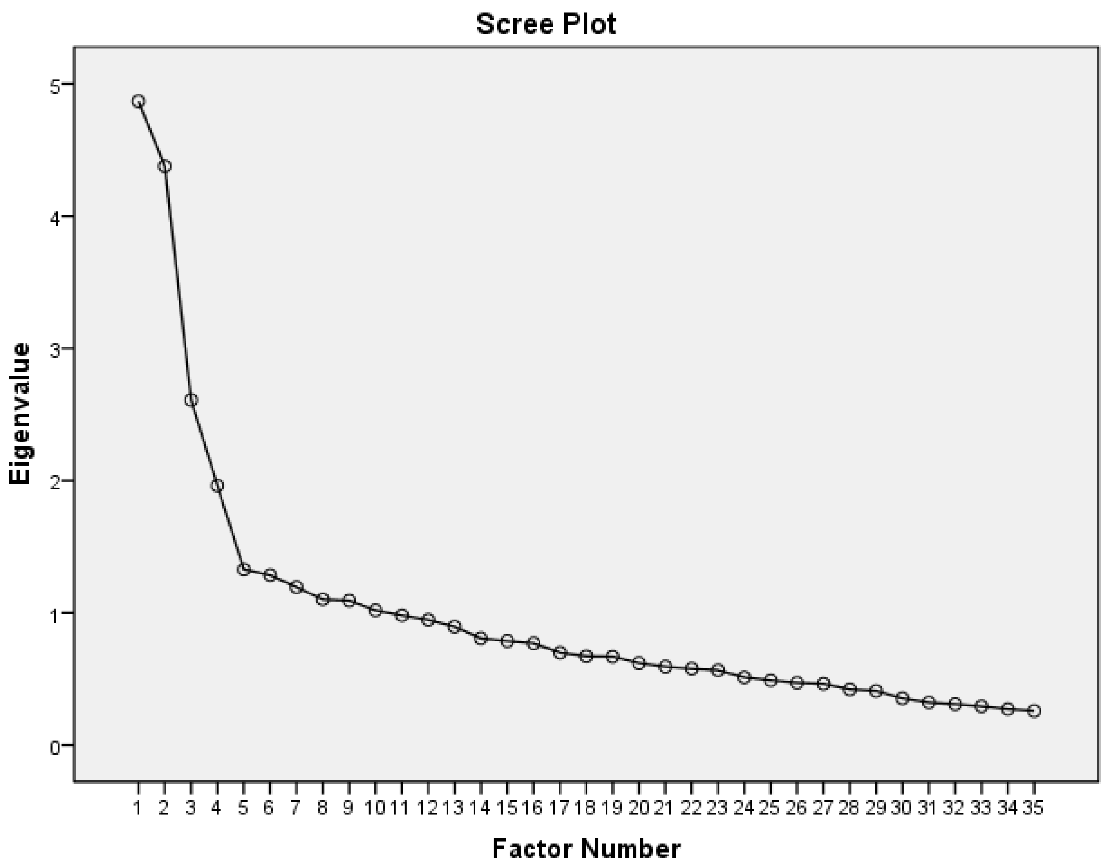

Figure 10.2. Scree plot for EFA sample data

Table 10.8

PASW 18 EFA pattern matrix loadings for factors with eigenvalues greater than 1 (n=251)

	Factor solution pattern matrix for eigenvalues > 1									
Item	1	2	3	4	5	6	7	8	9	10
Tent1	-	-	-	.85	-	-	-	-	-	-
Tent2	.39	-	-	-	-	-	-	-	-	-
Tent3	-	-	-	.49	-	-	-	-	-.27	-
Tent4	-	-	-	.26	-	-	-	-	-	.44
Tent5	-	-	.85	-	-	-	-	-	-	-
Tent6	-	-	.48	-	-	-	-	-	-	.25
Tent7	-	-	.49	-	-	-	-	-	-	-
Law1	.70	-	-	-	-	-	-	-	-	-
Law2	.59	-	-	-	-	-	-	-	-	-
Law3	.39	-	-	-	-	-	-	-	-	.62
Law4	-	-	.34	-	-	-	-	.35	-	-
Law5	-	-	-	-	1.06	-	-	-	-	-
Law6	-	-	-	-	-	-	-	-	-	.28
Law7	-	-	-	-	-	-	-	-	.69	-
Law8	-	-	-	-	-	-	-	-	-	-
Soc1	-	.84	-	-	-	-	-	-	-	-
Soc2	-	-	-	-	-	-	.32	-	-	-
Soc3	-	.78	-	-	-	-	-	-	-	-
Soc4	-	.69	-	-	-	-	-	-	-	-
Soc5	-	.32	-	-	-	-	-	-.48	-	-
Soc6	-	-	-	-	-	-	-	-	-	-
Soc7	-	.48	-	-	-	-	-	-	-	-
Soc8	-	.50	-	-	-	-	-	-	-	-
Meth1	-	-	-	.56	-	-	-	-	-	-
Meth2	.40	-	-	-	-	-	-	-	-	-
Meth3	.38	-	-	-	-	-	-	-	-	-
Meth4	-	-	.58	-	-	-	-	-	-	-
Meth5	-	-	-	-	-	-	-	-	-	-
Meth6	-	-	.42	-	-	.27	-	-	-	-
Emp1	-	-	-	-	-	-.45	-	-	-	-
Emp2	.45	-	-	-	-	-	.58	-	-	-
Emp3	-	-	-	-	-	.25	-	.65	-	-
Emp4	-	-	-	-	-	.56	-	-	-	-
Emp5	-	-	-	-	-	-	-	-	-	-
Emp6	-	-	-	-	-	.43	.56	-	-	-

Note: Loadings less than .3 suppressed.

While the eigenvalue-based factor solution did not provide a satisfactory solution, the associated data did provide evidence from which a holistic judgment could be made about the target range of factors to be explored. Both a one and two-factor solution were rejected on the grounds that they would provide under-defined solutions (i.e., multiple factors would have significant cross-loadings). Solutions with seven or more factors were also rejected as, like the ten factor solution, they were likely to lack explanatory power (i.e., the factors would contain too few items). Based on the scree plot data, a solution around four and five factors appeared to be most parsimonious. Costello and Osborne (2005) recommend exploring items either side of such an estimate. As a result the three, four, five and six-factor solutions were all explored and judged on the following criteria:

- the relative χ^2 data as reported by the PASW 18 software and the calculated χ^2/df of each model,
- the total percentage of variance explained by that number of factors,
- The number of items failing to load above .3 to any factor,
- The number of items with cross loadings of more than .3 to multiple factors,
- The number of factors that contained three or more items with loadings above .5,
- The final criteria by which the factor solutions were judged was by the interpretability of the resulting factors structure.

The three-factor solution accounted for 34% of the explained variance. The reported PASW 18 chi square for the solution was χ^2 (493, n=251) = 821.54, p <0.05. The normed chi square was calculated to be (χ^2/df) 1.67. The pattern matrix (see Table 10.9a) showed seven items that failed to load to factors above the .3 threshold and three items that had cross loadings of .3 or more across two factors. All three of the extracted factors had three or more items with loadings above .5.

The four-factor solution accounted for 39% of the explained variance. The reported PASW 18 chi square for the solution was χ^2 (461, n=251) = 642.69, p <0.05. The normed chi square was calculated to be (χ^2/df) 1.39. The pattern matrix (see Table 10.9b) showed three items that failed to load to factors above the .3 threshold and three items that had cross loadings of .3 or more across two factors. Three of the extracted factors had three or more items with loadings above .5 while the forth factor only contained two items with loadings above .5.

The five-factor solution accounted for 43% of the explained variance. The reported PASW 18 chi square for the solution was χ^2 (430, *n*=251) = 577.38, *p* <0.05. The normed chi square was calculated to be χ^2/df = 1.34. The pattern matrix (see Table 10.9c) showed six items that failed to load to factors above the .3 threshold and three items that had cross loadings of .3 or more across two factors. Three of the extracted factors had three or more items with loadings above .5 while one factor had two items with loadings above .5. The last factor only contained a single item

The six-factor solution accounted for 47% of the explained variance. The reported PASW 18 chi square for the solution was χ^2 (400, *n*=251) = 505.48, *p* <0.05. The normed chi square was calculated to be χ^2/df = 1.26. The pattern matrix (see Table 10.9d) showed three items that failed to load to factors above the .3 threshold and three items had cross loadings of .3 or more across two factors. Three of the extracted factors had three or more items with loadings above .5 while one other factor had two items with loadings above .5. The two remaining factors each contained one item with a loading above the .5 threshold however one of these factors only contained a single item.

Table 10.9a

PASW 18 EFA pattern matrix loadings for three-factors solution (n=251)

	Factors		
Item	1a	2a	3a
Tent1	-	.36	-
Tent2	.64	-	-
Tent3	-	.37	-
Tent4	-	.57	-
Tent5	-	.68	-
Tent6	.39	.51	-
Tent7	-	.59	-
Law1	.62	-	-
Law2	.62	-	-
Law3	.60	-	-
Law4	.33	-	-
Law5	-.31	.46	-
Law6	-	.44	-
Law7	-.47	-	-
Law8	-.40	-	-
Soc1	-	-	.77
Soc2	.33	-	-
Soc3	-	-	.81
Soc4	-	-	.72
Soc5	-	-	.42
Soc6	-	-	-
Soc7	-	-	.45
Soc8	-	-	.47
Meth1	-	-	-
Meth2	-	-	-
Meth3	.42	-	-
Meth4	-	.58	-
Meth5	-	-	-
Meth6	-	.47	-
Emp1	-	-	-
Emp2	.62	-	-
Emp3	.51	-	-
Emp4	-	-	-
Emp5	.44	.31	-
Emp6	-	-	-

Table 10.9b

PASW 18 EFA pattern matrix loadings for four-factors solution (n=251)

	Factors			
Item	1b	2b	3b	4b
Tent1	-	-	.76	-
Tent2	.59	-	-	-
Tent3	-	-	.47	-
Tent4	-	.42	-	-
Tent5	-	.62	-	-
Tent6	-	.66	-	-
Tent7	-	.51	-	-
Law1	.67	-	-	-
Law2	.65	-	-	-
Law3	.52	.32	-	-
Law4	.32	-	-	-
Law5	-.39	.37	-	-
Law6	-	.41	-	-
Law7	-.50	-	-	-
Law8	-.44	-	-	-
Soc1	-	-	-	.75
Soc2	.36	-	-	-
Soc3	-	-	-	.80
Soc4	-	-	-	.71
Soc5	-	-	-	.45
Soc6	-	-	-	-
Soc7	-	-	-	.52
Soc8	-	.31	-	.55
Meth1	-	-	.65	-
Meth2	-	.32	-	-
Meth3	.40	-	-	-
Meth4	-	.43	-	-
Meth5	-	-	-	-
Meth6	-	.45	-	-
Emp1	-	-	-	-
Emp2	.59	-	-	-
Emp3	.47	-	-	-
Emp4	-	.33	-	-
Emp5	-	.51	-	-
Emp6	-	.40	-	-

Table 10.9c

PASW 18 EFA pattern matrix loadings for five-factors solution (n=251)

	Factors				
Items	1c	2c	3c	4c	5c
Tent1	-	.35	-	.67	-
Tent2	.59	-	-	-	-
Tent3	-	.35	-	.41	-
Tent4	-	.59	-	-	-
Tent5	-	.65	-	-	-
Tent6	.31	.54	-	-	-
Tent7	-	.54	-	-	-
Law1	.64	-	-	-	-
Law2	.67	-	-	-	-
Law3	.69	-	-	-	-
Law4	.40	.32	-	-	-
Law5	-	.49	-	-	-
Law6	-	.43	-	-	-
Law7	-.52	-	-	-	-
Law8	-.39	-	-	-	-
Soc1	-	-	-	-	.76
Soc2	-	-	-	-	-
Soc3	-	-	-	-	.80
Soc4	-	-	-	-	.71
Soc5	-	-	-	-	.45
Soc6	-	-	-	-	-
Soc7	-	-	-	-	.51
Soc8	-	-	-	-	.54
Meth1	-	-	-	.62	-
Meth2	-	-	-	-	-
Meth3	.36	-	-	-	-
Meth4	-	.56	-	-	-
Meth5	-	-	-	-	-
Meth6	-	.44	-	-	-
Emp1	-	-	-	-	-
Emp2	.51	-	-	-	-
Emp3	.53	-	-	-	-
Emp4	-	-	-	-	-
Emp5	.32	.31	-	-	-
Emp6	-	-	.73	-	-

Table 10.9d

PASW 18 EFA pattern matrix loadings for six-factors solution (n=251)

	Factors					
Items	1d	2d	3d	4d	5d	6d
Tent1	-	-	-	-	.70	-
Tent2	.52	-	-	-	-	-
Tent3	-	.32	-	-	.43	-
Tent4	-	.58	-	-	-	-
Tent5	-	.65	-	-	-	-
Tent6	-	.58	-	-	-	-
Tent7	-	.59	-	-	-	-
Law1	.67	-	-	-	-	-
Law2	.64	-	-	-	-	-
Law3	.59	.33	-	-	-	-
Law4	-	-	.34	-	-	-
Law5	-.43	.44	-	-	-	-
Law6	-	.42	-	-	-	-
Law7	-.52	-	-	-	-	-
Law8	-.50	-	-	-	-	-
Soc1	-	-	-	-	-	.77
Soc2	.36	-	-	-	-	-
Soc3	-	-	-	-	-	.80
Soc4	-	-	-	-	-	.71
Soc5	-	-	-	-	-	.44
Soc6	-	-	-	-	-	-
Soc7	-	-	-	-	-	.50
Soc8	-	-	-	-	-	.53
Meth1	-	-	-	-	.61	-
Meth2	-	.32	-	-	-	-
Meth3	.40	-	-	-	-	-
Meth4	-	.55	-	-	-	-
Meth5	-	-	-	-	-	-
Meth6	-	.40	-	-	-	-
Emp1	-	-	-	-	-	-
Emp2	.52	-	-	-	-	-
Emp3	-	-	.77	-	-	-
Emp4	-	-	.30	-	-	-
Emp5	-	.32	-	-	-	-
Emp6	-	-	-	.72	-	-

As can be seen in the summary table, as the number of included factors increased the percentage of variance explained increased, and the normed chi square improved (Table 10.10). However as the solutions added factors the number of factors which did not have three or more items loading above .5 increased, which reduced the explanatory power of the solution. In examining the pattern matrix of all the factor solutions it can be seen that the first and last factor of the three-factor model is almost unchanged across all four possible solutions. The variations between the models occur as the second factor is teased apart. Between the four-factor solution and the six-factor model, these middle factor items are separated out until by the six-factor solution the fourth factor contains no items with loadings above .5.

Table 10.10

Summary table of EFA criteria

Number of retained factors	Percentage of explained variance (%)	Normed chi square (χ^2/df)	Number of items with loadings less < .3	Number of items with cross loadings > .3	Number of factors with less than 3 items with .5
3	34	1.64	7	3	0
4	39	1.39	3	3	1
5	43	1.31	6	3	2
6	47	1.26	3	3	3

While the six-factor solution had the most optimum parameters in four of the five categories it did not have strongly loading factors. By comparison the four-factor solution was an improvement on the three-factor model in all but the last category and, crucially, retained more factors with strong loadings (i.e., three or more items loading above .5) than either the five-factor or six-factor solutions. As all four solutions showed a similar separation of the items all four were modelled with AMOS 18 software and examined with the second data set.

10.4.5. CFA of data driven models

To ensure the data was appropriate for factor analysis it was examined using PASW 18 software. The KMO measure of sampling adequacy was an acceptable (.78) and the Bartlett’s test of sphericity was significant (χ^2 (n = 251) = 2613, $p < .05$). The diagonals of the anti-image correlation matrix were all above .5 and 30 of the 35 items had one or more correlations above .3. These collectively indicated that the data was appropriate for use with factor analysis techniques.

For each model the items were constrained to the latent variables identified in the EFA solutions. Items that had cross-loadings in excess of .3 were constrained to the factor with which they had greatest loading (e.g., in the four-factor model, law item five was constrained to factor two). In the cases where both loadings were within .5 of each other the largest absolute value was used but the modification indices for the model were examined to see if an improved fit would occur if the item was loaded to the other factor. In the case of factors with only one item, the next highest loading item to that factor was allowed to cross load so that AMOS could calculate the model parameters.

To establish indicators for each latent variable a Cronbach's alpha was run with the items grouped to each latent variable and the item with the strongest item-total correlation was set to one. An initial extraction was run using maximum likelihood and the regression weights examined to identify if any items had weightings greater than one. Any items with weightings greater than one were assigned as the indicator item before the extraction was re-run and the resulting factor loadings and goodness of fit data examined.

10.4.5.1. CFA of three-factor model

The Cronbach's alpha analysis of the three-factor model identified empirical item two as the indicator for factor one, tentative item five as the indicator for factor two, and social item four as the indicator for factor three. When the initial extraction was run the factor three item, social three, had a regression weighting of 1.05 and so was made the indicator item for that factor. The model also excluded six items that had failed to load to any of the factors above the .3 threshold. As a result, social item six, method items one, two and five, and empirical item one and four were not included in the model (see Figure 10.3).

The goodness of fit for the data driven three-factor model was questionable (χ^2 (374, n=251) = 863.39, p <0.05, χ^2/df = 2.49, RMSEA = .08, TLI = .68, CFI = .71). The EFA pattern matrix had indicated seven factors needed to be excluded from the model while the CFA data identify four extra items that failed to load to the three factors above the .3 threshold (see Table 10.10a). The model had no significant correlations between the factors. The data-derived three-factor model was an improvement on the NOS concepts model but did so by excluding almost a third of the items and so was not considered further as an interpretable solution.

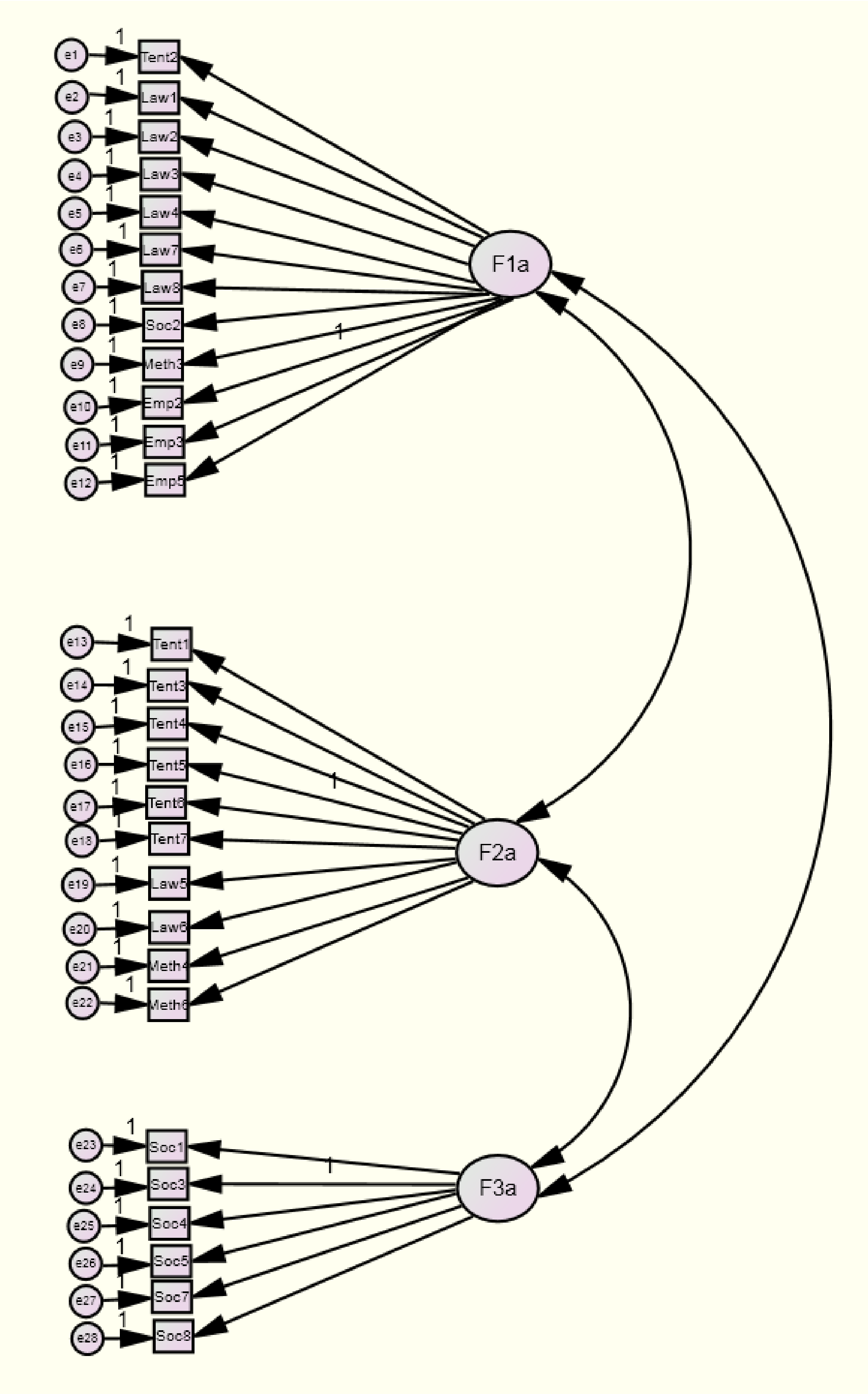

Figure 10.3. Three-factor solution model with scale indicators

Table 10.10a

AMOS 18 CFA loadings for three-factor model (n=251)

		Factor		
Item	F1a	F2a	F3a	α
Tent2	.46	-	-	
Law1	.49	-	-	
Law2	.59	-	-	
Law3	.48	-	-	
Law4	.56	-	-	
Law7*	-.42	-	-	
Law8	-.37	-	-	
Soc2	.25	-	-	
Meth3	.56	-	-	
Emp2	.71	-	-	
Emp3	.56	-	-	
Emp5	.16	-	-	
				.52(.65*)
Tent1	-	.40	-	
Tent3	-	.27	-	
Tent4	-	.52	-	
Tent5	-	.80	-	
Tent6	-	.51	-	
Tent7	-	.62	-	
Law5	-	.42	-	
Law6	-	.50	-	
Meth4	-	.62	-	
Meth6	-	.29	-	
				0.76
Soc1	-	-	.66	
Soc3	-	-	.75	
Soc4	-	-	.77	
Soc5	-	-	.62	
Soc7	-	-	.53	
Soc8	-	-	.49	
				.80

Note: *Cronbach's alpha when item Law 7 deleted.

10.4.5.2. CFA of four-factor model

The Cronbach's alpha analysis of the four-factor model identified law item three as the indicator for factor one, tentative item five as the indicator for factor two, tentative item one as indicator for factor three and social item three the indicator for factor four. When the initial extraction was run the factor one item, empirical two, had a regression weighting of 1.32 and so was made the indicator item for that factor. The model excluded three items that had failed to load to any of the factors above the .3 threshold in the EFA analysis. As a result, social item six, method item five, and empirical item one were not included in the model (see Figure 10.4). As law item five had similar cross-loading values to both factor one (-.39) and factor two (.37) in the EFA data the model was run with the item loaded to factor one. The modification indices for that item were examined and indicated a better fit would occur if the item was loaded to factor two. Based on this data the item was loaded to factor two.

The goodness of fit for the data-driven four-factor model was questionable (χ^2 (425, n=251) = 1105, p <0.05, χ^2/df = 2.41, RMSEA = .08, TLI = .66, CFI = .68). The EFA pattern matrix had indicated three items needed to be excluded from the model and the CFA data identified three additional items that failed to load to factors above the .3 threshold (see Table 10.10a). While the CFA sample was more heavily constrained than the EFA sample the loadings for the four factors were consistent with only factor three failing to meet the three items loading above .5 threshold (see Table 10.10b). The model also indicated a correlation between factor two and three (.41), reflecting a close relationship between the two factors which were combined in the three-factor model. The four-factor data derived model represented an improvement on the NOS concepts model. The four-factor model seemed to present the most 'clean' and most well-defined factor solution.

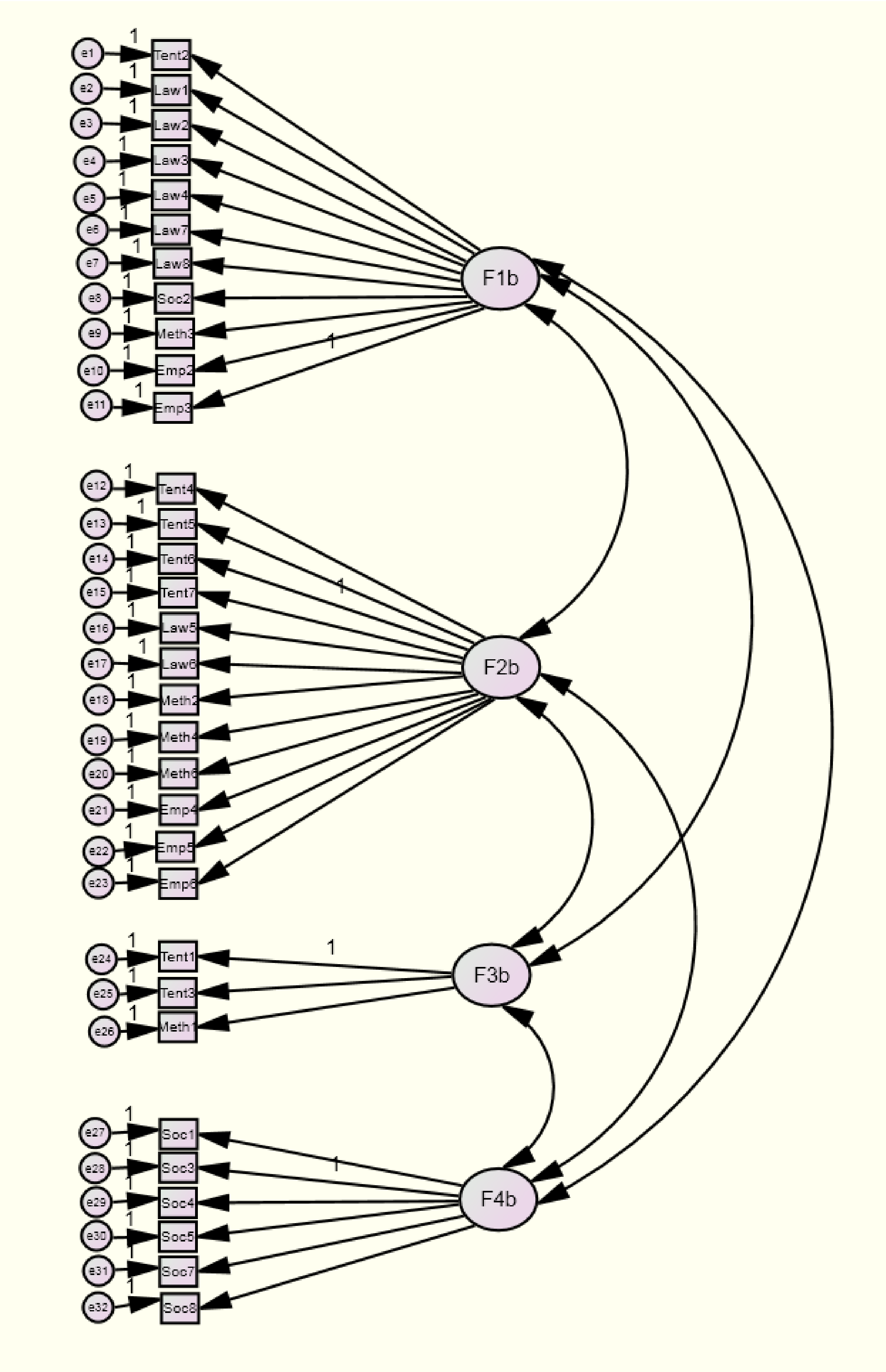

Figure 10.4. Four-factor solution model with scale indicators

Table 10.10b

AMOS 18 CFA loadings for four-factor model (n=251)

	Factors				
Items	F1b	F2b	F3b	F4b	α
Tent2	.45	-	-	-	
Law1	.49	-	-	-	
Law2	.59	-	-	-	
Law3	.48	-	-	-	
Law4	.56	-	-	-	
Law7*	-.42	-	-	-	
Law8	-.37	-	-	-	
Soc2	.26	-	-	-	
Meth3	.56	-	-	-	
Emp2	.71	-	-	-	
Emp3	.56	-	-	-	
					.51 (.66*)
Tent4	-	.47	-	-	
Tent5	-	.76	-	-	
Tent6	-	.57	-	-	
Tent7	-	.66	-	-	
Law5	-	.39	-	-	
Law6	-	.51	-	-	
Meth2	-	.18	-	-	
Meth4	-	.61	-	-	
Meth6	-	.35	-	-	
Emp4	-	.26	-	-	
Emp5	-	.31	-	-	
Emp6	-	.44	-	-	
					.76
Tent1	-	-	.75	-	
Tent3	-	-	.58	-	
Meth1	-	-	.47	-	
					.63
Soc1	-	-	-	.66	
Soc3	-	-	-	.76	
Soc4	-	-	-	.77	
Soc5	-	-	-	.62	
Soc7	-	-	-	.53	
Soc8	-	-	-	.49	
					.80

Note: *Cronbach's alpha when item Law 7 deleted.

10.4.5.3. CFA of five-factor model

The Cronbach's alpha analysis of the five-factor model identified empirical item two as the indicator for factor one, tentative item six as the indicator for factor two, tentative item one as indicator for factor four and social item three the indicator for factor five. Factor three only contained one item which was designated as the indicator. When the extraction was run no other items exceeded the indicator item regression weights and so the model indicators were not modified.

The model excluded the six items that had failed to load to any of the factors above the .3 threshold during the EFA. As a result, social items two and six, method items two and five and empirical items one and four were not included in the model (see Figure 10.5). In addition empirical item five had similar cross-loading values to both factor one (.32) and factor two (.31) in the EFA data. The model was run with the item loaded to factor one and the modification indices for that item were examined and indicated a better fit would occur if the item was loaded to factor two. Based on this data the item was loaded to factor two.

The goodness of fit for the data driven five-factor model was questionable (χ^2 (366, *n*=251) = 878.22, $p < 0.05$, χ^2/df = 2.40, RMSEA = .08, TLI = .70, CFI = .73). While the CFA model was more constrained than the EFA pattern matrix some of the loadings improved however the overall model did not capture the CFA data characteristics. Two of the factors (F3c and F4c) had less than three items meeting the .5 loading criteria and one item failed to load above the .3 threshold (see Table 10.10c). The model indicated correlations between factor two and three (.44) and two and four (.44) indicating that the solution was not a good representation of the data set. Other model measures, including the Cronbach's alphas and the single item factor in the solution, also indicated that the overall fit for the five-factor model was insufficient and should be rejected.

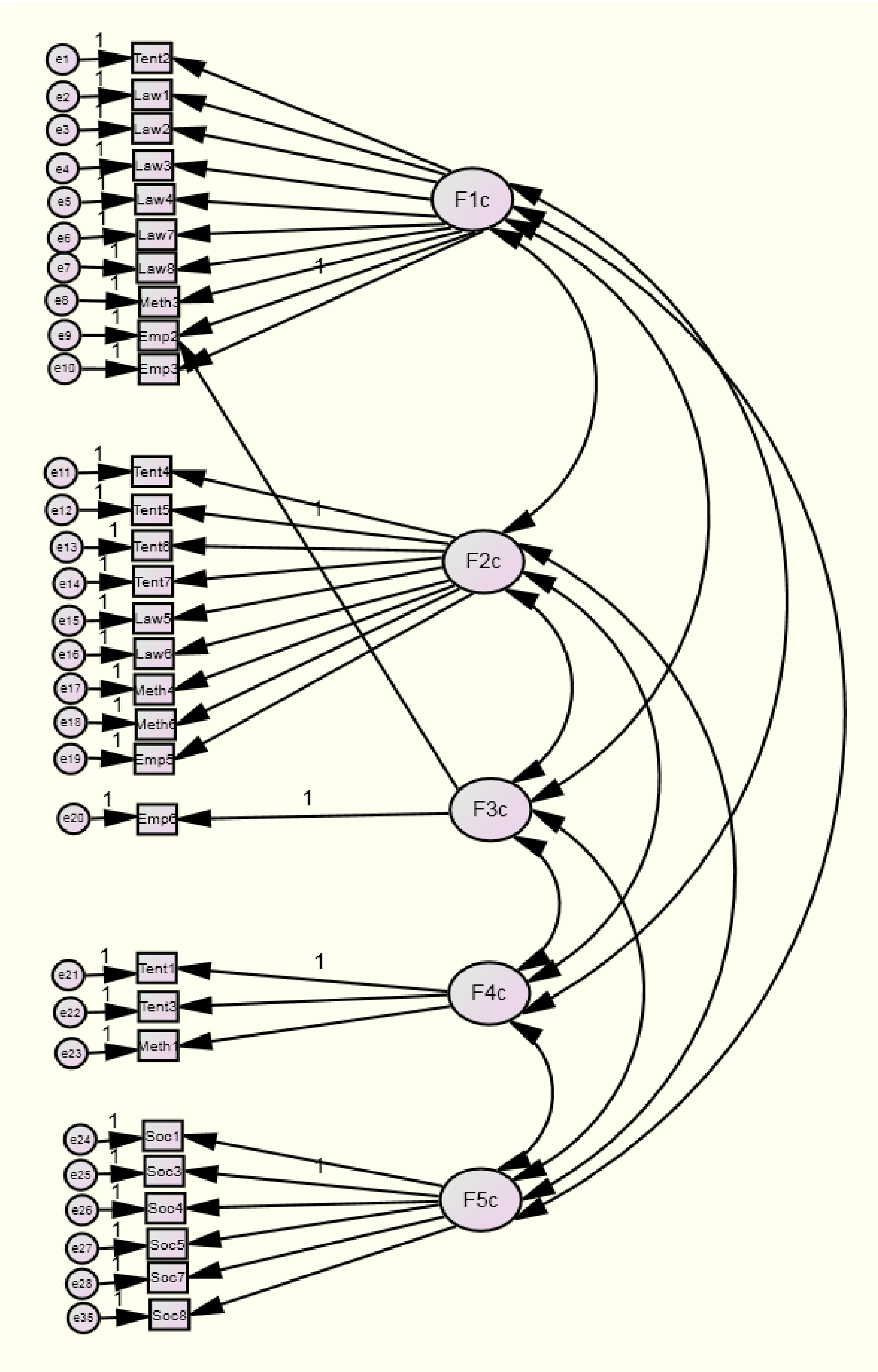

Figure 10.5. Five-factor solution model with scale indicators

Note: As factor four contained only a single item (Emp6), the item Emp2 was selected as the next highest loading item (.29) to cross-load to the factor for calculation purposes.

Table 10.10c

AMOS 18 CFA loadings for five-factor model (n=251)

	Factor					
Item	F1c	F2c	F3c	F4c	F5c	α
Tent2	.44	-	-	-	-	
Law1	.50	-	-	-	-	
Law2	.60	-	-	-	-	
Law3	.46	-	-	-	-	
Law4	.55	-	-	-	-	
Law7*	-.41	-	-	-	-	
Law8	-.39	-	-	-	-	
Meth3	.56	-	-	-	-	
Emp2	.69	-	-	-	-	
Emp3	.57	-	-	-	-	.48 (.65*)
Tent4	-	.49	-	-	-	
Tent5	-	.77	-	-	-	
Tent6	-	.54	-	-	-	
Tent7	-	.66	-	-	-	
Law5	-	.41	-	-	-	
Law6	-	.51	-	-	-	
Meth4	-	.62	-	-	-	
Meth6	-	.33	-	-	-	
Emp5	-	.28	-	-	-	.76
Emp2[I]	-	-	.07	-	-	
Emp6	-	-	.98	-	-	.48
Tent1	-	-	-	.78	-	
Tent3	-	-	-	.57	-	
Meth1	-	-	-	.45	-	.63
Soc1	-	-	-	-	.66	
Soc3	-	-	-	-	.75	
Soc4	-	-	-	-	.76	
Soc5	-	-	-	-	.62	
Soc7	-	-	-	-	.54	
Soc8	-	-	-	-	.50	.80

Note: *Cronbach's alpha when item Law7 deleted; [I]Item allowed to cross-load for calculation purposes only.

10.4.5.4. CFA of six-factor model

The Cronbach's alpha analysis of the six-factor model identified empirical item two as the indicator for factor one, tentative item five as the indicator for factor two, law item four as the indicator for factor three, tentative item one as the indicator for factor five and social item four as the indicator for factor six. Factor four only contained one item which was designated as the indicator. When the extraction was run for factor three, empirical item three had a regression weighting of 1.06 and for factor six, social item three had a regression weighting of 1.05. For each case the higher loading items were made the indicator item for their respective factors.

The model also excluded three items that had failed to load to any of the factors above the .3 threshold during the EFA. As a result, social item six, method item five and empirical item one were not included in the model (see Figure 10.6). In addition law item five had similar cross-loading values to both factor one (-.43) and factor two (.44) in the EFA data. The model was run with the item loaded to factor two and the modification indices for that item were examined and indicated that this was the best fit. Based on this data the item was loaded to factor two.

The goodness of fit for the data driven five-factor model was questionable (χ^2 (448, *n*=251) = 1083, p <0.05, χ^2/df = 2.42, RMSEA = .08, TLI = .65, CFI = .69). As with the other models the more constrained CFA data did reproduce some of the EFA results but overall did not represent a suitable fit for the data. Three of the factors (F3d, F4d and F5d) had less than three items meeting the .5 loading criteria and four items failed to load above the .3 threshold (see Table 10.10d). The lone item in factor four also returned a loading greater than one, indicating that the item explained more than 100% of the variance seen in the item. This is a situation that should not occur but is an artefact of the factor only containing a single item and should be seen as strong evidence to reject the model.

The model indicated a strong correlation between factor one and three (.84) indicating that these items may be better represented by a single construct. The model also indicated correlations between factors two and five (.45) and two and four (.38). In addition four of the six Cronbach's alphas were questionable or unacceptable and adds to the evidence that the solution is not an effective model of the data.

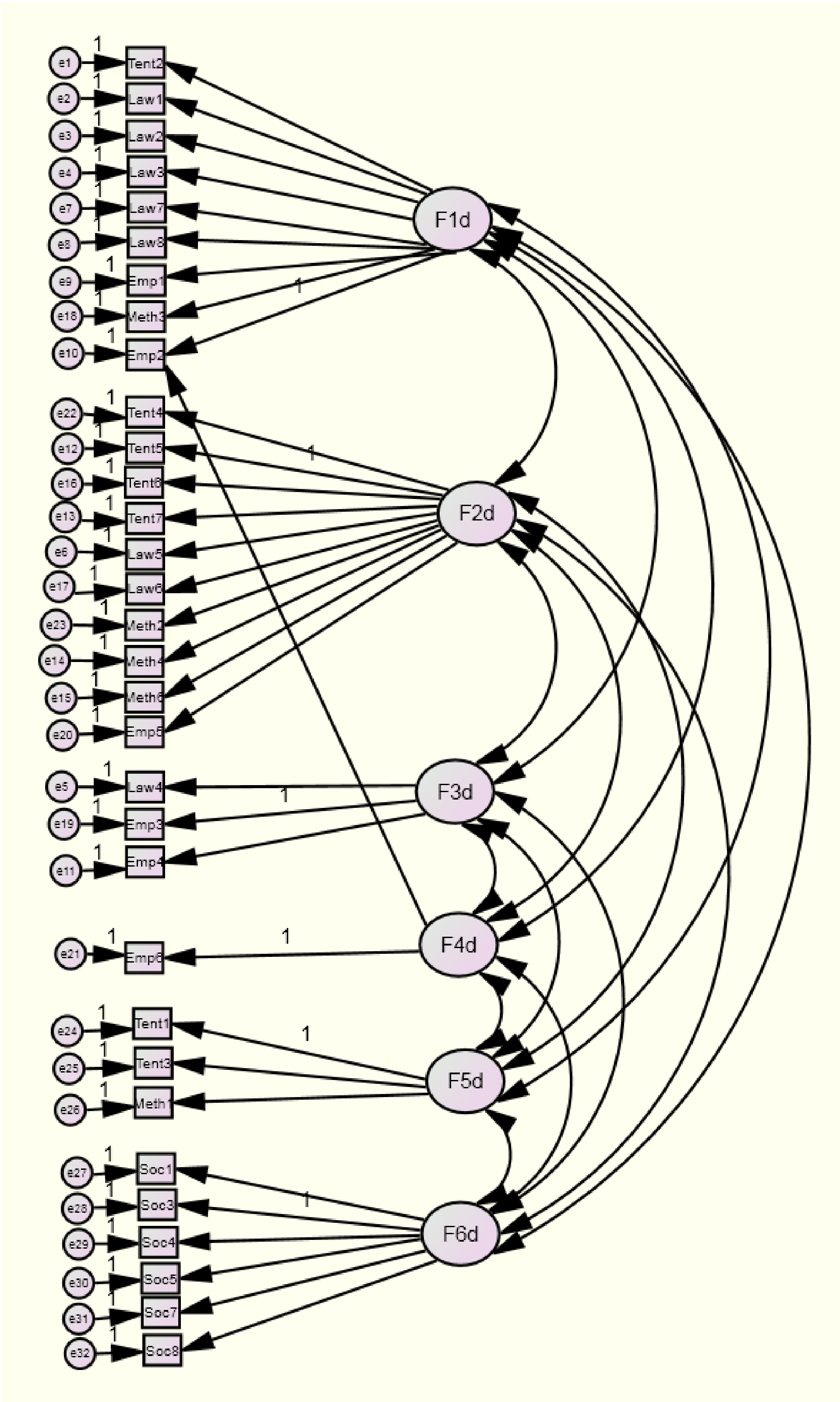

Figure 10.6. Six-factor solution model with scale indicators

Note: As factor four contained only a single item (Emp6), the item Emp2 was selected as the next highest loading item (.27) to cross-load to the factor for calculation purposes.

Table 10.10d

AMOS 18 CFA loadings for six-factor model (n=251)

	Factor						
Item	F1d	F2d	F3d	F4d	F5d	F6d	α
Tent2	.45	-	-	-	-	-	
Law1	.51	-	-	-	-	-	
Law2	.60	-	-	-	-	-	
Law3	.46	-	-	-	-	-	
Law7*	-.41	-	-	-	-	-	
Law8	-.39	-	-	-	-	-	
Soc2	-.01	-	-	-	-	-	
Meth3	.56	-	-	-	-	-	
Emp2	.70	-	-	-	-	-	.30 (.54*)
Tent4	-	.48	-	-	-	-	
Tent5	-	.77	-	-	-	-	
Tent 6	-	.55	-	-	-	-	
Tent7	-	.66	-	-	-	-	
Law5	-	.40	-	-	-	-	
Law6	-	.51	-	-	-	-	
Meth2	-	.16	-	-	-	-	
Meth4	-	.61	-	-	-	-	
Meth6	-	.34	-	-	-	-	
Emp5	-	.29	-	-	-	-	.74
Law4	-	-	.59	-	-	-	
Emp3	-	-	.67	-	-	-	
Emp4	-	-	.26	-	-	-	.49
Emp2[I]	-	-	-	.05	-	-	
Emp6	-	-	-	1.14	-	-	.35
Tent1	-	-	-	-	.80	-	
Tent3	-	-	-	-	.44	-	
Meth1	-	-	-	-	.56	-	.63
Soc1	-	-	-	-	-	.62	
Soc3	-	-	-	-	-	.77	
Soc4	-	-	-	-	-	.53	
Soc5	-	-	-	-	-	.49	
Soc7	-	-	-	-	-	.66	
Soc8	-	-	-	-	-	.76	.80

Note: *Cronbach's alpha when item Law7 deleted; [I] [I]Item allowed to cross-load for calculation purposes only.

10.5. Substantive Interpretation

Comparing the fit indices for all four potential models indicated little distinction between them (see Table 10.11). All the factor solutions had RMSEA values of .8, normed Chi square values below 2.5, TFI values below .7 and CFI values below .8. As the fit indices were not able to significantly distinguish the alternative solutions models the resulting structures were examined to identify which model produced the most parsimonious solution. The three-factor model did provide a factor structure that produced three well defined factors with three or more items loading above .5, however it did so by excluding eleven of the items and so was rejected. The addition of more factors did reduce the number of items that were excluded but in the case of the five and six-factor models this did not significantly improve the fit of the models and introduced a single item factor. The decision was made to explore the four-factor model further as this model excluded the least number of items without having to introduce a single item factor.

Table 10.11

Summary of model parameters (n=251)

Number of factors	Normed chi square ($\chi2$/df)	RMSEA	TLI	CFI	Number of items with loadings <.3	Number of factors with 3 or more items >.5	Number of factors containing one item
NOS	4.09	.08	.54	.57	9	3	0
3	2.49	.08	.68	.71	11	3	0
4	2.41	.08	.66	.68	6	3	0
5	2.40	.08	.70	.73	7	3	1
6	2.42	.08	.65	.67	7	3	1

The items associated with each of the models' four factors were examined to identify potential common themes that could be linking the items. The three highest loading items for each factor were examined first and possible common themes to these items were identified by the researcher as being the possible construct definition. The remaining items were then examined to see if they supported the emergent construct. Items which failed to load above the .3 threshold during the CFA were not included in the analysis

10.5.1. Factor one interpretation

The first factor contained ten factors with loadings above .3 and five items with strong loadings above .5. The two strongest loading items were empirical item two (.71) and law item two (.59). The other three items, law item four, scientific method item three and empirical item three, all had loadings of .56. As such all five were used to identify the potential underlying construct.

A common theme identified between the five items (see Table 10.12a) was that they referred to the process of science. Empirical item two described explanations being derived from evidence and law item two referred to laws describing observations made about the world. The other three items also described aspects of how science worked. Law item four referred to the role of new discoveries, scientific method item three referred to solving scientific questions and empirical item three reaffirmed that explanations were based on evidence.

The remaining items also made references to the process of science. Tentative item two and law item three referred to the role of new evidence in changing explanations. Law item one referred to science being used to explain patterns. Law items seven and eight were both negatively loaded to the factor as students had given naive responses to these items; however both also appeared to reflect students' beliefs about the scientific process with proven theories reflecting laws that existed independent of the human mind.

The construct relating these items was therefore defined as the process of science; how science works. The items in this factor reflected students' beliefs about the way scientists went about gathering data and identifying explanations that were consistent with an objectively attainable reality. The process identified was that many different methods are used to gather evidence which is then interpreted by scientists to provide explanations. These explanations can go from being theory to law when enough evidence exists to confirm they match the observed behaviour of nature.

10.5.2. Factor two interpretation

The second factor contained ten factors with loadings above .3 and three items with strong loadings above .5. These items were similar to the first factor items but did not possess a clear interpretable common construct (see Table 10.12b). The strongest loading items were tentative item five (.76), tentative item seven (.66) and scientific method item four (.61). These items each made references to the certainty of scientific knowledge referring to established scientific explanations, the ideas contained in science textbooks and the exactness of scientific experiments. The items' means indicated that the majority of students recognised that absolute certainty of knowledge in each of these aspects was not possible.

However, a number of the remaining items and their means were not consistent with this interpretation. Items such as tentative four ('the study of science finds out the absolute truth about the world around us') and law five ('if a scientific theory is proven right it becomes a scientific law') had low scoring means indicating that students believed that absolute knowledge was possible. The items appeared to be united by what students thought science was trying to achieve, discovering the 'truth' about the world around us. This appeared to be tempered by the recognition that this was not possible as experiments could not be exact and new evidence could change the explanations.

As no clear defining terms emerged from the items in this factor the student annotations were examined to see if further insight could be gained. Four of the items in this factor were annotated by three of the students. As noted in section 10.1 one student wrote 'they should' beside law item six, scientific method item four and tentative item seven. Another student also noted beside scientific method item four that if the results were repeated then the experiment was accurate. These annotations gave an indication that students had a distinction between what they thought scientists should be aiming to achieve and what they thought it could currently achieve.

While this idea could not be further tested until the interviews, the construct was tentatively labelled 'purpose of science; what science does'. Unlike the process items, these items were deemed to be more orientated to what students believed science was trying to achieve, while at the same time they indicated the students' awareness of the limitations of what science can currently achieve. The items in this construct appeared to represent students' views that due to limitations (human and technological) explanations of phenomena were never absolutely true as new evidence could be found to challenge or change the explanation. However, students also appeared to believe science is trying to attain the true answer, which they equated to proven scientific laws.

10.5.3. Factor three interpretation

The third factor only contained three items which were all examined to identify a unifying construct. The three items closely resembled items loaded to factor two and also asked about the absoluteness of scientific knowledge and the exactness of experiments (see Table 10.12c). While the items in factor two were mixed with items probing other concepts these items only appeared to be probing students' ideas about certainty of scientific knowledge. As such the construct was labelled 'certainty of scientific knowledge' with all three items having means just above the neutral value and comparatively large standard deviations. This indicated that students were divided about how certain and absolute scientific knowledge was. The similarity to factor two was also reflected in the correlation (.42) between the two constructs indicating they did share a number of underlying features.

10.5.4. Factor four interpretation

The final factor contained six of the social NOS concept items with five of the items loading above .5. This construct appeared to be the only factor that reflected one of the intended concepts (see Table 10.12d). , the role of beliefs in science and so was labelled 'scientists' beliefs'. Like the third factor, the mean and standard deviations indicated significant uncertainty and disagreement amongst the students as to how much of an effect beliefs and values had on scientific research. This insight was supported by the annotations of social item seven that personal beliefs should not affect scientists but do.

Table 10.12a

Summary of substantive interpretation of construct 1

Item	Construct - Process of science; how science works Statement	Loading	*M (SD)*
Tent2	New evidence can change scientific explanations.	.45	7.51 (1.37)
Law1	Scientific theories are created to explain patterns in the world around us.	.48	6.71 (1.48)
Law2	Scientific laws are created to describe observations made about the world around us.	.59	6.55 (1.44)
Law3	New evidence can change scientific laws.	.48	7.07 (1.52)
Law4	Scientific laws are temporary and change with new discoveries.	.56	6.75 (1.63)
Law7	Scientific laws exist in nature before we discover them.	-.42	3.07 (1.73)
Law8	Scientific theories become scientific laws when enough evidence is collected.	-.37	4.03 (1.57)
Meth3	Many different scientific methods are used to solve scientific questions.	.56	6.85 (1.29)
Emp2	Scientific explanations are created by interpreting evidence.	.71	6.59 (1.31)
Emp3	Scientific explanations are based upon evidence.	.56	6.74 (1.48)
Summary	*Many different methods are used to collect evidence which is interpreted to form explanations. Explanations describe the world and change with new discoveries. Proven theories become law.*		

Table 10.12b

Summary of substantive interpretation of construct 2

Item	Statement	Loading	*M (SD)*
	Construct - Purpose of science; what science does		
Tent4	The study of science finds out the absolute truth about the world around us.	.47	4.53 (2.11)
Tent5	Established scientific explanations are absolutely correct.	.76	5.94 (1.76)
Tent6	Established scientific explanations never change.	.57	6.67 (1.67)
Tent7	Science books contain absolutely true explanations.	.66	6.09 (1.90)
Law5	If a scientific theory is proven right it becomes a scientific law.	.39	4.41 (1.74)
Law6	Scientific laws are fixed and work everywhere.	.51	5.39 (1.93)
Meth4	Professional scientific experiments produce exact results.	.61	5.59 (1.74)
Meth6	There is one scientific method that is always used in the same way.	.35	5.84 (1.72)
Emp5	Scientific explanations do not need evidence to be accepted.	.31	7.31 (1.77)
Emp6	Scientific evidence does not need to be interpreted.	.44	6.38 (1.75)
Summary	*Explanations are not absolutely true (due to human error). Science tries to measure an absolute reality (laws).*		

Table 10.12c

Summary of substantive interpretation of construct 3

Item	Construct - Certainty of scientific knowledge Statement	Loading	*M (SD)*
Tent1	Science can never determine absolute truth.	.76	5.66 (2.21)
Tent3	No scientific explanation can be proven to be absolutely true.	.58	5.97 (2.09)
Meth1	Professional scientific experiments can never be measured exactly.	.46	5.27 (1.91)
Summary	*We can't get absolute answers.*		

Table 10.12d

Summary of substantive interpretation of construct 4

Item	Construct - beliefs in science Statement	Loading	*M (SD)*
Soc1	Personal beliefs influence scientific observations.	.66	5.05 (1.92)
Soc3	Values and beliefs influence scientific research.	.76	5.31 (1.92)
Soc4	Experience and beliefs affect the interpretation of scientific data.	.77	5.45 (1.75)
Soc5	Scientific research is not affected by personal beliefs.	.62	4.47 (2.08)
Soc7	Personal values and goals do not influence the way scientific evidence is interpreted.	.53	5.19 (1.90)
Soc8	Personal beliefs do not influence scientific explanations.	.49	5.14 (1.99)
Summary	*Beliefs influence scientists (but they shouldn't).*		

10.6. Quantitative Summary

The questionnaire data indicates that the NOS subgroups, outlined at the start of the research, did not appear to be the underlying constructs guiding students' beliefs about science. Rather than eliminating items until the data matched the expected model, the researcher investigated alternative factor solutions. The resulting data-driven model suggests that students' beliefs about science are guided by their conceptualisation of the purpose and process of science. They are also shaped by their views on the certainty of knowledge and the role scientists' beliefs have in the scientific process.

The model, while in some way supported by the students' annotations and the pilot study, is not enough on its own to justify rejecting the expected NOS model. To ensure the four-factor model adequately represented student beliefs, purposively selected students were identified to take part in interviews. These interviews set out to probe the participants' views on the five NOS themes and to establish if their concepts about the way science worked were better represented by the alternative constructs. In addition to gaining additional detail about students' beliefs about science, the interviewed participants were also asked about the items that failed to load to the model (see Table 10.12e). However as the interviews only lasted 30 minutes, none of the students were explicitly asked about empirical item four.

Table 10.12e

Items that failed to load above .3 during EFA or CFA with the four-factor model

Item	***Items that failed to load*** Statement	*M (SD)*
Soc2	Scientific data can be interpreted in many different ways.	6.65 (1.43)
Soc6	Past explanations do not affect new scientific explanations.	5.76 (1.91)
Meth2	There is no single scientific method.	6.69 (1.90)
Meth5	The scientific method refers to the steps all scientific experiments follow.	4.66 (1.60)
Emp1	Scientific evidence only includes data from the world around us.	4.12 (1.80)
Emp4	Scientific explanations are created before data is collected.	5.64 (1.84)

CHAPTER 11 – PHASE TWO: QUALITATIVE STUDY

Overview

The purpose of the second phase of the study was to explain why students provided different responses to the questionnaire items. More specifically, it was to identify students' underlying reasoning behind the distinct patterns detected in their responses to different items on the questionnaire, and the resulting factor loadings. Previous research suggested that differences in students' understanding of NOS concepts would explain differences in students' responses to the questionnaire items. As the responses did not appear to match this expectation, this phase of study sought to explore students' understanding of NOS concepts in an attempt to provide insights into why their questionnaire responses differed.

A purposive sampling procedure identified students for interviews based on their questionnaire responses. Specifically, a sample of students who had high (considered indicative of informed NOS beliefs), middle (considered indicative of transitional NOS beliefs), and low (considered indicative of naive NOS beliefs) questionnaire scores were selected. To rank the students the questionnaire item responses were scored and grouped based on the four-factor solution identified in the quantitative phase of the study (i.e., F1, F2, F3 and F4). The summed score of these four factors was used to separate students into the three scoring categories and representative samples were selected (n=22).

11.1. Analysis of Questionnaire Data and Formation of Qualitative Groups

Of the 532 initial participants, 53% indicated on their consent forms that they would be willing to participate in an interview. As noted by Teddlie and Yu (2007), researchers who conduct mixed method studies often constrain themselves unnecessarily by their initial research questions and poorly define their sampling methods. As a solution, they suggested that researchers should use the first phase of the study to develop an appropriate sampling frame that is well defined and use it to address the research questions that emerged from the initial phase. Based on these recommendations, and to identify a range of representative student samples, the means and standard deviations of the questionnaire items from the first phase of the study a were used to select students (Hodis, 2011, May). This sequential, stratified, purposive sampling process identified high, medium and low scoring students. To calculate the scores: (1) individual item responses were compared to the response mean for that item and scored, (2) an average factor score was calculated based on the items loading to each factor, and (3) a total score was generated by adding the factor scores. Students were identified as high, middle and low scoring based on the total score.

In stage one, participants were assigned a score for each item using the mean and standard deviation of each item. Students were given a score of “1” if their response was one standard deviation below the mean, “2” if the response was within one standard deviation of the item mean or “3 if it was greater than one standard deviation above the mean. For example, the mean for tentative item one was 5.7 and the standard deviation was 2.2. Thus, students were given a “1” if their scores were less than 4 (5.7 - 2.2 = 3.5), a “2” if their scores were between 4 and 8, or a “3” if their scores were greater than eight (5.7 + 2.2 = 7.9). For example, student S001’s response to tentative item one was “8”, they received a score of “3”, whereas student S002’s response was a “3” and so they received a score of “1”.

In the second stage, the average factor score was calculated by summing the scores of the items that loaded under each of the four factors identified in the EFA (see section 10.4) and dividing that sum by the number of items in that factor. For example, factor four (social) consisted of six items: one, three, four, five, seven and eight. The scores from stage 1 for each of these items was summed and divided by six for each participant. However, items that did not load to any factor on the EFA model were excluded and did not contribute to the total score calculation. Thus, social five, scientific method five and empirical item one did not load to any factor in the EFA model so were excluded and did not contribute to the total score calculation.

In the final stage, the total score for each student was created by summing their four factor scores. The mean and standard deviation of the total score was calculated (M = 7.9, SD = 0.8) and used to identify students with high scores (i.e., scores greater than 8.7), medium score (i.e., scores between 8.7 and 7.1) and low scores (i.e., scores less than 7.1).

Twenty students from each group were identified and invited to participate in an interview. An excess amount of students were selected to allow for attrition rates. The code numbers of these students were given to a research assistant who converted the code number into a list of names which were given to the respective science Head of Departments (HoD) of each school. This step ensured that the researcher was unaware of which sample group a student belonged to during the interviews process. Of the 60 students approached, 22 students returned their signed parental consent forms prior to the interviews and were present at school on days that interviews took place.

11.1.2. Participants

Group one consisted of six high scoring students, three male and three female, with a median age of 15. Group two consisted of eleven middle scoring students, three male and eight female, with a median age of 15. Group three consisted of five low scoring students, two male and three female, also with a median age of 15. The average factor scores and total scores of each student is given below (see Table 11.1). The students were each given a study information sheet (see Appendix E) and a parental consent form was sent home to be signed by their guardian prior to the interview taking place (see Appendix G).

Table 11.1

Interview participants' four-factor model scores and total scores

Group	Student	Score F1	F2	F3	F4	Total
Group 1	S292	2.0	2.6	2.8	3.0	10.5
	S355	2.0	2.4	3.0	2.0	9.8
	S033	2.3	2.4	1.7	3.0	9.6
	S021	2.2	2.2	2.2	2.3	9.2
	S112	1.5	2.7	1.5	2.7	9.2
	S105	2.1	2.2	2.8	2.3	9.2
Group 2	S093	2.0	2.0	2.2	2.3	8.6
	S377	2.3	2.5	1.3	2.7	8.5
	S089	2.3	2.0	2.3	2.0	8.2
	S085	1.9	2.2	2.0	1.3	8.0
	S462	2.1	2.0	2.2	1.7	7.8
	S468	2.0	1.9	1.5	2.3	7.6
	S202	2.0	1.9	2.0	2.0	7.6
	S081	2.3	2.1	1.0	2.0	7.5
	S154	2.0	2.0	1.5	2.0	7.5
	S024	1.4	1.8	1.7	1.7	7.4
	S469	2.1	2.2	1.8	1.3	7.2
Group 3	S289	2.0	2.3	1.0	1.7	7.0
	S378	2.0	2.1	1.0	2.0	7.0
	S279	1.5	1.3	2.2	1.7	6.8
	S410	1.9	2.2	1.0	1.3	6.6
	S054	2.2	1.6	1.0	1.0	5.9
Actual (*n*=502)						
	Highest	2.5	2.9	3	3	10.5
	Lowest	1.3	1.3	1	1	5.9
	Mean	2.0	2.0	1.9	2.0	7.9
	SD	0.3	0.3	0.4	0.4	0.8
Sample (*n* =22)						
	Highest	2.3	2.7	3	3	11
	Lowest	1.4	1.3	1	1	5.9
	Mean	2.0	2.1	1.8	2.0	8.0
	SD	0.3	0.3	0.6	0.5	1.2

11.2. Materials

Interview Protocol

The semi-structured interviews consisted of five open-ended questions and related follow-up questions for probing students' NOS beliefs. The initial question asked students to describe "what is science?" The follow up questions included (i) how is science different/similar to other subjects, and (ii) how does school science compare to actual scientific practice. These questions were used to probe students' beliefs about the tentative and empirical NOS concepts.

The second question asked students about the characteristics of scientists. Students were asked if they believed scientists were imaginative, and if so in what ways. They were also asked if they believed scientists were affected by their beliefs. These questions were used to probe students' beliefs about the social NOS concept.

The third question asked students to reflect on their previous responses and asked what factors had influenced their beliefs about science. This question aimed to address the second main research question: What factors do students identify as having influenced their understanding of NOS concepts? It was introduced after the first two questions to allow students to reflect on what they believed and why.

The fourth question asked students to first define what they thought the term 'scientific law' meant. Then they were asked what the term 'scientific theory' meant. Finally, students were asked to explain how the two terms were related to each other. This section of the interview was used to probe students' beliefs about the law and theory NOS concepts.

The fifth question asked students to define the term 'scientific method' and to explain its use in science. These questions were used to probe students' beliefs about the scientific method NOS concepts.

In addition to the main questions students were also asked to explain their understanding and responses to five of the six items that failed to load during the EFA and CFA analysis of the four-factor model (i.e., social items two and six, scientific method items two and five and empirical item one). As noted in section 10.6, due to time constraints empirical item four was not explicitly addressed with any of the students. The responses to the five items that were included were examined to identify substantive reasons why the items failed to load as expected.

11.3. Procedure

The individual interviews took place in rooms set aside by the staff of each school during each student's normal science lessons. Each interview was allocated a 30-minute timeslot to minimize disruptions to classes and students' learning. The students were reminded of the study's purpose and goals prior to the interview commencing and were asked to confirm they still consented to take part in the study. The start of each interview involved the students stating their name and school to provide an audio check for the tape recorder before the interview proper began.

The researcher posed the core interview questions to each student and then used subsequent probing questions to explore the students' reasoning and meaning for each response based on their initial responses (Freyberg & Osborne, 2001). This format allowed the researcher to respond more dynamically to each individual's response and to explore unexpected data. For example, student S024, in explaining their understanding of empirical evidence, explained how science could be used to examine ghosts, "So if you told me that you've found evidence of ghosts I wouldn't say 'no,' I'd look at it at least, and if it was just a curtain moving or something and the window was open, like then you can question it or whatever" (S024). The researcher used a probing question following this response, and others like it, to gain insights into students' perspectives. This technique is also noted by Seidman (2006) as being useful in the initial stages of the data analysis as the specific follow-up questions reflect the tentative ideas the researcher is forming about the subjects' beliefs and views.

To help minimise the possible risks of researcher distortion and bias during the interviews, the researcher used the interview checklist developed by Bell, Osborne and Tasker (2001). This checklist helped ensure:

- the questions asked the students about their beliefs and understanding of each concept;

- the questions developed during the interview were based on the student's answers, rather than on preconceived notions of what the students should know;
- the reasoning behind each student's answer was explored with appropriate supplementary questions to ensure the interviewer fully understood the student's response;
- students are given sufficient time to formulate their answer before being prompted by the researcher;
- students are given a chance to clarify their understanding of each question;
- an appropriate power relationship was established and maintained between the interviewer and the interviewee.

These considerations were applied to ensure that the respondents felt they were able to express themselves in a collaborative process without the risk of judgment or ridicule (Fleer & Robbins, 2003). The researcher relied on his experience as a secondary school science teacher to help ensure that an appropriate rapport was developed with the students. Relying on this experience helped the researcher be alert to appropriate lines of questioning and helped facilitate honest responses from students. By the researcher showing respect and attention to the student answers, students who began the interview process hesitantly were willing participants as the interview discussions progressed.

During the interviews, pen and paper was available for the students to use. Fleer and Robbins (2003) indicate that students' responses often reflect the limitations of their language rather than of their understanding of the topic, so pen and paper offer students a chance to express graphically what they may not be able to express verbally. Three students used these resources during the interviews to help illustrate and explain their answers. All of the interviews were recorded and a research assistant transcribed the interviews verbatim. The researcher also took notes during the interviews and made post-interview reflection notes which were used alongside the interview transcripts during the coding process. A sample interview is included in Appendix H.

11.3.1 Coding of Interview Data

During the interviews the researcher formulated additional questions based on students' responses. A researcher's tentative interpretations of the students' conceptions and beliefs affect the form of these new questions (Seidman, 2006). While this is not part of the official coding process, this ‘in interview’ coding has a significant effect on what data was collected from each student and should be recognised as the precursor of the coding process (Seidman, 2006).

The post-interview coding process consisted of three stages. The first stage involved the researcher reading each individual transcript while listening to the audio recording of the interview and making individual profile notes (Seidman, 2006). During this process, particular relevant quotes from the individual were highlighted and the responses to each open-ended question and additional questions were used to create a tentative profile about each student’s view of specific NOS concepts. For example, the initial coding notes for student S024’s responses to law and theory questions were ‘Starts with legal and then moves to physical … Law is what happens. Theory would probably or could happen … T→ L with evidence’. On a separate sheet, the emergent coding categories from all the students were collated under the five open-ended question headings. These initial coding categories, derived from the interview data, are presented in Table 11.2 for each question.

The same procedure was carried out for the five questionnaire items that were identified as problematic. For these items, common themes were noted (e.g., for empirical item one ‘scientific evidence only includes data from the world around us’, student S033 stated that, “It can come from anywhere, not just the world around us. It can come from space.”) Notes were made beside each response to indicate what appeared to be the issue with each question, (e.g., for students S033, the researcher wrote ‘world around us = just earth’ next to the statement).

Table 11.2

Initial coding categories

Interview question	Initial collection of coding terms			
What is science?	Explanation Everything Discovery Empirical	Knowledge Logical Discipline Repeatability	Big questions Deeper level Fact	Applications Falsifiability Altruistic
How is science different from other subjects?	Explains Applications Vastness	Logical Natural Experiments	Facts Exact Universal	Mechanistic Non-human Fun
Comparing school science to 'real' science?	Basics Learning Stimulates	Known facts Gain knowledge Like real science	Simplified Career	Motivation Continuum
Do beliefs affect scientist?	Ideal Logical Curious	Imaginative Control beliefs Creative	Interested Competitive Conflict	Find errors Peers
What does law and theory mean?				
Law	Proven Fact Set	Evidence Physics Formula	Limits Rule Specific	Unsure
Theory	Unproven Idea Lacks evidence	Thought Hypothesis Explanation	Evolution Assumption Imagination	Unsure Global Pushing boundary
What does scientific method mean?	Steps Process Uncertain	Experiments Discovery Evidence	Application Diagrams Conclusions	Actions Civilization
What has influenced your beliefs?	Teacher School	Family Documentaries	Books Interest	Religion Movies

The second stage of the coding process involved comparing all of the students' responses to each question. To do this, the researcher used NVivo 9 software to create five nodes related to the primary interview questions with branching nodes created to capture the responses to additional questions. These nodes were;

- What is science (i.e., students' descriptions of science)
  - How does science compare to other topics
  - How authentic is school science
- Do beliefs affect scientist (i.e., what traits do students associate with scientists)
  - Are scientists imaginative/creative
  - Are scientists affected by their beliefs
- What do the terms law and theory mean
- What does the term scientific method mean
- What has influenced your view of science

The students' responses for the five questionnaire items were also reviewed, and where appropriate, comments that related to the primary questions were copied into the respective nodes.

During this stage, a second researcher with science expertise co-coded an interview with the researcher and helped identify relevant text sections. A second transcript was then coded by both researchers independently and then compared. Where discrepancies existed, the reason for coding a specific piece of text to that category was discussed and changes to the coding process of the researcher made accordingly. This peer review was used to help enhance data validity (Merriam, 2009).

In the third and final stage of the coding process, the researcher identified the minimum number of coding categories needed to accommodate all the responses while ensuring that the categories remained an accurate representation of all the students' beliefs (Seidman, 2006). Each open-ended question node was printed out. The researcher reviewed the responses and categorised them using the categories identified in stage one. For each node, the text placed in each category was reviewed to identify categories that needed to be merged or divided. For example, the coding categories for 'what is science' were reduced to (1) explanations, (2) discovery, (3) discipline, (4) everything and (5) knowledge. Any coding category that contained only one student was examined to see if it could be merged with another category. If the category could not be merged, it was assigned to the category 'other', (e.g., the student responses coded in the scientific method categories action and application were placed together in the coding category 'other'). After this process was complete the researcher reviewed each student's complete transcript for any additional comments or contextual features that were relevant to the category a student response was coded to. This was done to ensure no additional data had been overlooked during the initial coding stages.

The researcher then tabulated the results for each open-ended question, sorting students by their scoring group (i.e., high, medium and low) and marking on the tables what response category each student was associated with. The resulting tables were reviewed as part of the analysis to identify if specific coding categories were associated with specific sample groups (e.g., did the high scoring sample students respond with the same category response to a given open-ended question). The researcher also created descriptions of each coding group based on the interview data. Any categories that were unique to a specific sample group were noted. A descriptive summary of the students' responses to the non-loading questionnaire items was also created. Finally, the second researcher with science expertise again reviewed the collective work to provide peer reviewed feedback about the appropriateness of the final coding categories (Merriam, 2009).

11.4. Coded Interview Results

In this section the students' responses to each open-ended interview question from the interview are described. The responses are coded into different categories with each category described and illustrated with student quotes to illustrate the participants' responses. For the open-ended questions that generated additional questions (e.g., the 'what is science' question), the additional questions are coded and described as sub sections. Specific additional coding procedures used for particular sections are described prior to the coding category descriptions.

11.4.1. What is science?

All the students were asked to describe ‘what is science’ with twelve students asked a follow up question ‘what does science set out to do’ in order to clarify their responses. This part of the interview was intended to elicit students’ overall view of science and to probe their beliefs about the certainty of scientific knowledge and the role of empirical evidence in building that knowledge. Four main response categories emerged from the interview data analysis (see Table 11.3). The first category consisted of comments in which participants indicated that science involved providing explanations, (e.g., “science is the learning of how things work” S021). The second category consisted of comments in which participants indicated that science involved the discovery of things, (e.g., “to me science is the nature of discovery”, S462). The third category consisted of comments in which participants indicated that science pertained to everything known and unknown, (e.g., “it's everything as we know it” S054). The last category consisted of comments in which participants associated science with the acquisition of knowledge, (e.g., “learning new stuff”, S202).

As this question was very broad, many students provided descriptions that included multiple categories. In situations in which a student gave a response that fitted into more than one category, the researcher coded the lesser-developed concept(s) as secondary categories (marked within parenthesis in the Table 11.3). In addition to the four coding categories used, five students, from across all three sample groups, initially described science in terms of subject disciplines, “the different topics. Like chemistry and physics and biology” (S355). However, in each case the students then provided more generalized descriptions, “just like finding out about how things work” (S355). As such, the discipline response was not coded as a unique category as no student used it as their only response to the question.

Table 11.3

Coding categories for what is science

Group	Student	Explanations	Discovery	Everything	Knowledge
		Coding category			
<u>Group 1</u>	S021	x		(x)*	(x)
	S033			x	
	S105				x
	S112	x			
	S292	x			
	S355	x	(x)		
<u>Group 2</u>	S024			(x)	x
	S081	x		(x)	
	S085	x			
	S089	x		(x)	
	S093		x		
	S154	x	(x)		
	S202				x
	S377	x		(x)	
	S462	x	(x)		
	S468	x	(x)	(x)	
	S469	x	(x)		
<u>Group 3</u>	S054			(x)	x
	S279				x
	S289		x	(x)	
	S378	x		(x)	
	S410	x		(x)	

Note: * Secondary coding category in parenthesis, (x).

Science as explanations

Fourteen students, from all three sample groups, identified ‘providing explanations’ as a primary definition of ‘what is science’. Science was seen as an important factor in helping us understand the natural world. Student S469 described its role as “To broaden our understanding of things around us, to help us get a better understanding of things, like what's happened in the past and like how they determine stuff that happens in the future.”

Students identified human curiosity and desire as being the driving force behind this search for explanations. For example, student S292 said, “I think it's just following the general human trend, that humans just have a general thirst for knowledge and are trying to figure out how things work, why things do what they do.”

Science was seen as unique by students in that it addressed a vast array of questions and issues. Student S085 said:

> *Not many other kind of subjects or whatever address kind of like, bigger questions about the world and stuff. The ones that like, kind of all humans naturally are curious about kind of thing, so ... it's kind of fulfilling that human curiosity. (S085)*

Through this, science was seen to help enhance peoples understanding of things they might otherwise take for granted. Student S468 said science set out to “educate people and [provide] knowledge of how stuff works rather than taking it for granted.” It was seen to do this through empirical evidence and logic. For example, student S085 explained that science was “kind of like the logical way of, explaining how the world around us came to be and works” and that it was “backed up by things that, we can prove, or figure out.”

Ten of these students also made secondary references to science in terms of one or more of the other categories. For example, during the initial part of the interview student S021 referred to science as “the learning of how things work and how things around you kind of work”, as “pretty much it’s like facts about things” and as “anything can be science.” While these students did include ideas about the other coding categories, they primarily focused their definitions on science’s ability to explain phenomena. For example, student S089 described how through “carrying out your own experiments … [we get] sort of a logical reason to our explanation to how everything is here and how everything works.”

Notably, some of the students who had completed the NOS course at college four made reference to Popper’s falsifiability concept in science. For example, student S377 noted “There's more doubts than I thought … I guess I thought it was more proving something to be right rather than proving something to be wrong.” However, not all students at college four accepted this concept and some still focused on science’s ability to prove an explanation, “something that you do to prove your belief on something” S469.

Science as discovery

Seven students indicated that science was about discovery but only two students provided this explanation as their primary response to the question. Student S093 and S289 focused their descriptions of science on the discovery of new things. Student S289 indicated that science tried to “find out what’s out there” and that this discovery involved “pretty much everything” and the purpose was to “describe the world to us better”. Student S093 emphasised that finding out what is out there was “not on the basis of this is a ten” but “on a deeper level, I guess, if that makes sense.... like on a, I would say more intellectual level, like finding out what's in space is science”. Both of these students focused their primary response on looking for new information and the idea that science is focused on discovery.

Science as everything

While ten students used the broad definition that science was everything, only one student, S033 in group one, used it as their only definition of science. Student S033 associated science with everything, noting that even science itself was part of science given that its practitioners and equipment could be studied, “I guess it's the tool and the thing we're watching, though … I guess cause, I don't know, it's just everything is science.”

Science as knowledge

Six students made reference to science as the acquisition of knowledge, with five using it as their main description. The students in this category identified the knowledge generated by science as being important. Students S024 and S054 focused on the facts of science, with student S054 stating “it's everything as we know it”, and S024 noting “pretty much its' like facts about things.” Both also recognised science as being ubiquitous with student S024 explaining later in the interview;

> *Pretty much everything is science I guess like even stuff like this one bit of plastic I guess. The bonds holding it together are that's science, the particles so it can be from absolutely anywhere even if you think about, if you went deep enough even your imagination because it's all about like things happening in your brain which is all science and anatomy and stuff like that. (S024)*

The remaining three students only gave brief definitions of what science was. Student S105 and S202 focused on science being about how knowledge was gained, “how they get information about the world and stuff like that” (S105). Student S279 only broadened their definition by referring to classroom experiences, “chemicals and stuff and about your body … the environment that we're living in.”

11.4.1.1. Additional question: How does science compare to other topics?

To further probe the students’ beliefs about ‘what was science’, all students were asked to compare science to other subjects. This question allowed specific aspects of students’ beliefs about scientific knowledge and discipline to be explored. From these descriptions, four coding categories about the differences emerged (see table 11.3). The first category distinguished science by its content range, (e.g., “you learn about all sorts of things”, S154). The second category distinguished science by its focus on explanations, (e.g., “history looks at what they did … science could look at why they did that, what was going on psychologically” (S292). The third category distinguished science by surface level differences, (e.g., “you do sort of like experiments to find the answer” (S378). The final category was defined as other and included three distinct answers given by three of the students, (e.g., “It’s just a lot more fun” (S033).

Students frequently used two additional concepts across all the coding categories. The first was that science focused on material not social aspects, (e.g., “science kind of explains things naturally … geography and history might explain culturally” (S093). The second was that science was evidence-based and factual, (e.g., “it kind of proves thing, but like other subjects can't really do" (S355). As these descriptions were common with all the coding categories, they are also discussed within the coding categories.

Table 11.4

Coding categories for differences between science and other topics

		Coding category			
Group	Student	Content range	Explain	Surface level	Other
Group 1	S021				x
	S033				x
	S105		x		
	S112			x	
	S292		x		
	S355		x		
Group 2	S024	x			
	S081		x		
	S085		x		
	S089		x		
	S093		x		
	S154	x			
	S202	x			
	S377			x	
	S462				x
	S468		x		
	S469			x	
Group 3	S054		x		
	S279			x	
	S289			x	
	S378			x	
	S410		x		

Content range difference

Three students in sample group two identified the content range of science as a distinguishing feature. These students viewed the breadth of science as its most distinguishing feature, "we're collecting facts about everything and like, pretty much yeah everything, how things act, how … there's no end to it really" (S024). This was compared to other topics which were seen to be limited in their range, “Like in maths it’s just maths and English it’s just English, but science you learn about all sorts of things” (S154).

Explanation difference

Ten students across all three sample groups identified the focus on explanations as a distinguishing feature of science. These students viewed the ability of science to provide explanations of why things happened as being unique, “science you kind of break it down more and find out reasons why stuff has happened” (S468). This was seen as distinct from other subjects like history which were considered to be focused on what happened, “Science is looking at how things work, why, but it's looking at, you know, the basis of the universe kind of thing. Like the plants, the trees, the human mind. Whereas history looks at what humans have done” (S292).

The explanations were also considered to be focused on material or natural explanations and were considered to be distinct from social or cultural explanations. For example student S355 said “science is more about material things, not social things”. Student S410 also explained that they would see the presence of feelings as a distinguishing characteristic between scientific and historical information, “if it was about people and their feelings and thoughts at the time”. Students commonly noted that scientific information was not completely certain but other knowledge, like history, was.

> *History is kind of like what has happened and that's kind of, yeah, cause that can be quite clear cut, but science is more kind of what we, we never can really know I don't think ... But it's what logically, you know, is most likely has happened ... I don't think all, you know, I don't think that is like 100%, but by all the evidence and stuff, it's like 99.99%. (S085)*

This was distinct from less factual subjects like English which were considered to be solely about opinion. As student S093 explained, “In English you can write an essay … about a million different things and make up complete crap … whereas science, it's sort of, more factual and law-based … English it's just more … as I said, opinion-based.”

These students also saw scientific knowledge as being built upon evidence, something that not all topics were seen to do, “I don't know, it just, it kind of proves things, but like other subjects can't really do” (S355). Some subjects, such as history, were seen to be evidence based, “they're both very factually based” (S292), but this was considered to be because once an event happened it could not be changed, “I mean I do history and I just find it as learning facts about what happened” (S093).

Surface differences

While a number of the other students made some surface comparisons as they answered this question, six students, from all three sample groups, gave responses that focused on surface level distinctions between science and other subjects. Four of the students focused on surface level differences noting that experiments were a key distinction, “you do sort of, sort of like experiments to find the answer” (S378). Students S279 and S289 by comparison made surface level connections. Student S289 identified that science had “lots of math to it” and that it involved “writing essays.”

The students who identified differences also noted that evidence was important in distinguishing science from non-science. When asked to compare historical evidence with scientific evidence student S469 explained;

> *I think there's something that makes it different because history is just, um, following events that have happened through, like, and not by, necessarily by evidence, by what people have said and by their stories … science is finding out stuff that might not necessarily be true, but they have a way to find out that it happened. (S469)*

The students in this category were aware of the importance of empirical evidence noting that it was a key factor in science, “they back a lot of their stuff up with facts that they've proven” (S378). However, they also distinguished non-human evidence from human evidence. For example, student S112 noted that for history “its more things that people make happen, not that are kind of there.” This sort of knowledge was also viewed to be more certain as it had happened, “history it's already been and so you either know it or you don't” (S377).

Other differences

Three of the students provided unique responses to the difference between science and other topics. As noted above, student S033 simply noted that science was more fun than other subjects and noted that it was different from other ‘fun’ subjects like computers in that a range of things could be done, “you can do nearly anything in science.” Student S462 also gave a unique response in identifying that science was ever-present, “to me science is pretty much everything” and that in the case of history “I would say history in itself is a form of science. I would say it's the science of discovering our past.” The student identified the reason for this prerogative as being due to their personal affiliation with science, “Because I'm a scientist at heart myself.” Finally student S021 also saw science in everything, but saw this primarily in terms of science being able to be adapted to other fields.

> *If you just did history, you can't really become like, say, a food technologist, or a chef as easy as it is from science … Because science you can just quickly apply it to the food technology or whatever, but with, you can't, you can't really apply history knowledge to something else that's not history. (S021)*

11.4.1.2. Additional question - How authentic is school science

Based on their responses to the first additional question, fourteen participants were also asked about how school science compared to their perception of professional applied science. Thirteen of the students who were asked identified that a difference existed and one student (S410) believed they were relatively similar. Of the students who identified a difference, two viewed school science as being focused on stimulating learners, (e.g., “school science is definitely trying to get us to discover and learn for ourselves”, S021). The remaining twelve students, including student S410, viewed school science as providing the basics of science that all students should know, (e.g., “in school science they kind of do basic science” (S279).

Table 11.5

Coding categories for focus of school science

Group	Student	Coding category: Stimulate learning	Coding category: Cover basics
Group 1	S021	x	
	S033	x	
	S292		x
	S355		x
Group 2	S089		x
	S202		x
	S377		x
	S462	x	
	S468		x
	S469		x
Group 3	S054		x
	S279		x
	S289		x
	S378		x
	S410		x

School science stimulates learning

Three students viewed school science as a means for encouraging students to investigate knowledge for themselves. For example students S021 said “school science it's definitely trying to get us to discover and learn for ourselves.” The students also noted that school science introduced new information, “you find out new stuff that you wouldn't know before” (S021) in an exploratory setting, *They'll give you the experiment for you to do yourself and you learn what's happening and stuff, rather than... If you read a book, it tells you what happens. But with the science at school you learn from doing it and that kind of helps make it, make it learn easier I guess. (S021)*

In doing this, school science was seen to stimulate the desire to learn about science or to allow students to identify that science was not for them.

In my opinion it makes us want to learn more, or makes us want to not learn more, depending on how you look at it. Like for me, for instance, like I'm set because of school. I know what I want to do. I want to be a physicist and things. (S462)

School science covers the basics

The other students associated school science with the basics of science. Student S279 stated that "I think they're different because in school science they kind of do basic science and stuff." The students noted that authentic science would involve a lot more, "I think science outside of school would be a lot more in-depth" (S468). Students also identified school science with proven knowledge and authentic science with the generation of new knowledge.

Science that we learn at school is more like stuff that's already known and has been proven and that's why we're learning it. But science out there is people mostly trying to prove theories or coming up with new things. (S378)

The students in this category viewed school science as providing an appropriate level of scientific knowledge. Student S469 explained, “It's a little bit limited, but it tells you like the stuff you should know at that age.” They identified this basic scientific knowledge as being important for everyday use, as student S054 gave an example of going to the doctor, “I mean it would be silly to know how you could talk to persons but not know what a body is … you can say, I am not feeling well, but I don't know what's hurting.” They also identified the basics with what future scientists needed in order to be successful. Student S089 explained, “I think school, like gives you, like the basics. So like, so that if you're going to continue in a science career then it's like, easier to discover your own scientific things.”

11.4.1.3. Summary

The students interviewed primarily associated science with providing explanations about the world in which we live. Students generally viewed science as a universal subject that was able to explain material things but which was not necessarily applicable to human activities and actions. Aspects of discovery and generating knowledge were also seen by the students as being key parts of science. It was distinguished from other subjects by being able to prove its claims. This was considered to be an important feature of science: that it was perceived to be exclusively about facts and not opinions. School science was also seen to be the preliminary stages of science that provided students with the known basics.

11.4.2. Scientists' traits?

All the students were asked about the roles of imagination and beliefs in science. This section of the interview was intended to probe the students' perception of the traits of scientists and the perceived role of social influences in science. In response to questions about imagination, three categories of responses emerged from the interview data analysis (see table 11.6a). In the first category, students viewed scientists as using their imaginations at limited times during the scientific process, (e.g., “It's always going, that's always going to go, that cycle. Imagination to fact, imagination to fact” S021). In the second category, students viewed scientists as using their imagination throughout the scientific process, (e.g., “you'd need a different kind of imagination, like you'd need to be able to interpret facts in a certain way”, S462). In the final category, students viewed scientists as using their imagination to identify new technologies and applications, (e.g., “you know how now Apple iTouch is coming up, they're still imagining something else better than that”, S202).

Table 11.6a

Coding of interview responses for scientists' imagination

		Coding category		
		Limited	Throughout	Applied
Group	Student			
Group 1	S021	x		
	S033	x		
	S105		x	
	S112	x		
	S292	x		
	S355			x
Group 2	S024	x		
	S081	x		
	S085	x		
	S089	x		
	S093	x		
	S154	x		
	S202	x		
	S377	x		
	S462		x	
	S468	x		
	S469	x		
Group 3	S054		x	
	S279			x
	S289	x		
	S378	x		
	S410	x		

In response to the question about scientists' beliefs, three categories of responses emerged from the interview data analysis (see table 11.6b). The students in the first category believed that scientists controlled or ignored their beliefs, (e.g., "It's going to be based on whatever new evidence you have … otherwise it wouldn't, it wouldn't be the fact" S021). The students in the second category believed that scientists used peers to reduce the effect of their beliefs, (e.g., "they'd have to like, trial it heaps. Like have heaps of experiments and get other people's opinions" S112). The students in the final category believed that scientists made choices based on their beliefs that affected how they acted and what they studied, (e.g., "You'd go for stuff that you think is interesting" S033).

Table 11.6b

Coding of interview responses for scientists' beliefs

		Coding category		
Group	Student	Controlled	Monitored	Choices
Group 1	S021	x		
	S033			x
	S105		x	
	S112		x	
	S292		x	
	S355	x		
Group 2	S024	x		
	S081	x		
	S085	x		
	S089		x	
	S093			x
	S154	x		
	S202		x	
	S377			x
	S462		x	
	S468			x
	S469			x
Group 3	S054		x	
	S279			x
	S289	x		
	S378			x
	S410	x		

11.4.2.1. Imagination

Imagination is limited

Seventeen students across all three sample groups indicated that imagination was important for science, but believed it was limited to specific roles in science. For example, student S292 said “Everybody has an imagination, it's just scientists have to be very careful when they choose to use it and when they don't.” The students in this category saw imagination as playing a role at the start of the scientific process in identifying things to study, “that's how lots of things came from people wondering and imagining what would happen if” (S021), and in deciding how to conduct the appropriate research, “if it's like new you've discovered then you'll probably need to think up a way of doing it” (S085).

However, students in this category did not view imagination as being necessary to interpret results, “I don't think this one relies as much on imagination or even really needs it” (S085). At this point imagination was expected to diminish as facts began to dominate. Student S021 illustrated this with a diagram (see Figure 11.1) and explained “as it goes through, the imagination gets smaller, and the fact gets larger,” (S021). Students recognised that not all experiments would be definitive, but believed a specific answer existed. Student S468 explained “there'll still be a right way, or a right answer. It's just finding out which ones aren't … in science there's always a right explanation, but how you get there might be different.” It was also possible that multiple methods may lead to the answer. Student S089 likened this with mathematics, “in maths how there's lots of different ways to get to one answer.”

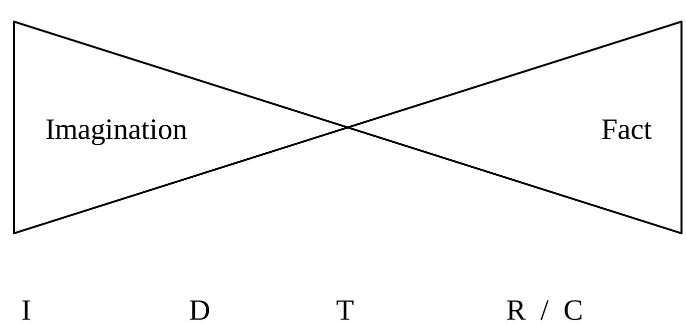

Figure 11.1. Adapted from the drawing by student S021

Note: I = imagination, D = design, T =testing, R = Results, C = Conclusion

If the correct answer was not obvious from the data, the students believed scientists would go back to imagination to devise a new way to approach the problem. Student S021 explained, “It depends how good the testing was. If it's murky … you'll have your kind of murky, kind of factish, and you go, ‘Well this still isn't right, I wonder if...’ and it goes again.” They perceived that imagination allowed scientists to discover new techniques for reaching their goals or for identifying variables that may have hindered the accuracy of the results. Student S410 suggested “you'd have to be really open-minded to everything that could affect each experiment.” Ultimately a definitive experiment was expected that led to a straight forward result, “it's sort of quite clear once you've got all your data” (S378).

In addition to controlling imagination, student S292 suggested scientists needed to focus their excess imagination somewhere. The student described Benjamin Franklin as an example of how scientific pursuits were balanced by more imaginative arts.

> *Like, like [Franklin]. He was rather committed to, um, you know, science in a way. I mean, he didn't exactly mean to get his kite hit by lightning, but it kind of happened. But he was also a renowned author. Um, even if people didn't actually know it was him because of a pseudonym. It's that kind of, that kind of balance that stops imagination from getting the better of you. (S292)*

While this student’s view was unique, it was consistent with the view that scientists needed to control their imagination so that they did not distort the facts they uncovered. As student S093 explained, “If there's evidence and facts then obviously, you know, facts are facts, you can't, you can't mess with facts.”

Imagination throughout

The three students in this category believed that imagination was used throughout the process. Like the first category, these students noted that scientists would need imagination to identify ways to collect data, "they would, of course, think about an experiment and think how they would prove something and use their imagination for it" (S054). However, the students in this category noted that imagination would also be involved in the interpretation of results. Student S054 and S279 indicated that this was a negative issue. Student S054 stated, "It's personal interpretation, that crucial part … where people can easily make a different, rules, from that," and student 462 noted, "You have to be able to interpret like the laws of nature in science to either prove you wrong or right."

To ensure that scientists interpreted finding correctly, student S054 identified repeatability as key "just as long as you could repeat the experiment, its good." Student S462 however noted that what scientific field was being examined was an important consideration,

> *I think it, it depends on the science. For instance, like something like theoretical science, you, yeah, you need to have the greatest imagination possible. For instance like Stephen Hawkins and stuff ... But I think with, um, something like history, because you're digging for facts, I don't think you need as much imagination as such. I'd say you'd need a different kind of imagination, like you'd need to be able to interpret facts in a certain way. (S462)*

For the more factual sciences, student S462 noted that imagination and interpretation would still work together, "they work hand in hand as the discovery progresses, 'cause as you like get proven wrong, you need to interpret it and imagine more what could possibly be there." Student S105 also noted that results would need imagination and interpretation: "They might not know what it's telling them completely." As a result scientists would need imagination to help them connect ideas, "They might have to, like, think of the, like um, putting 2 and 2 together, thinking about, um, the trends, or how it goes and stuff like that."

Applied imagination

The remaining two students associated imagination with the application of science and the development of new ideas and technology. Student S279 associated imagination with the creativity displayed by scientists and inventors in movies, “I've seen a lot of movies and scientists, I always see them trying to like get different results from stuff and that.” This was then also linked to invention and the creation of new thing, “say chemicals, trying to find different, how to combine a different chemical with another one.” Student S355 also associated imagination with novelty, “people, like, famous scientists, like if they've thought of these crazy inventions.” Imagination was seen by both these students to be something that allowed science to develop and make use of new discoveries, “Maybe to improve it, or do something else with it” (S355).

11.4.2.2. Beliefs

Beliefs are controlled

Eight students from across all three sample groups indicated that scientists needed to control their beliefs. For example, student S081 said, “I reckon scientists should be there to explain why things happen and not be affected by what they believe,” and student S410 explained that “I think that a good scientist wouldn't be influenced by what their personal beliefs were.” These students recognised that scientists were affected by beliefs, “I think it would be. Just like every job” (S033), but they identified it as something scientists would control, “I think if they were a professional kind of like very well-disciplined scientist, it shouldn't” (S085).

Students indicated that beliefs needed to be controlled to prevent scientists from releasing false information. For example, student S081 stated: “If the scientist is influenced by their beliefs, then it's kind of like telling a lie to everyone else. Because they might believe it, but it's not actually true.” This was seen to have dangerous repercussions as student S081 went on to explain, “It will change what the world thinks and it could be completely wrong.”

Being affected by beliefs was also perceived as poor practice as it would limit what the scientists investigated. For example student S355 said, “If they believe that one way's true they might be so intent on getting that way and then not look at other things.” Student

S410 noted that scientists may also be tempted to alter the facts to match their beliefs, “It's probably a bad thing … ‘cause it would mean that they would, like, say something's right or wrong and then it wouldn't necessarily be … they might change the facts.”

The concern that beliefs might alter facts was the primary reason why these students thought beliefs would need to be controlled. As student S355 explained “I think science isn't about what you believe; it's just about what actually is, it's about fact.” However the control of beliefs was not universally seen to be always possible. As student S085 noted the control of beliefs was more likely to be an ideal than an absolute, “like in theory it shouldn't, but in practice, that kind of thing will be very hard to stop.”

Beliefs are monitored

Seven students from across all three sample groups viewed beliefs as something that the scientific community monitored and compensated for by reviewing each other’s work. For example student S089 noted that “I think there's always some bias in like, yeah, every scientist there's probably some, like, you kind of prefer one answer to the other so you sort of find what evidence that proves that answer” but identified other scientists as a way to compensate for that “I guess just more scientists with different views doing the same thing at the same time.”

As with the previous category beliefs were considered to affect the actions of scientists. Student S202 noted “They’ll try and prove it more than if they didn't believe in it” and student S292 said, “Everyone is affected by what they want to do, what they want to achieve.” However students in this category did not believe people could internally control the influence of their beliefs. For example student S462 explained “I think there are people that could say they can, and would do their best to, but I feel that like your personal beliefs will always role, have a role to play in it … I don't think it's entirely possible to get rid of your beliefs in something.”

The students in this category saw the repeatability of experiments and multiple scientists working on similar projects as the key to controlling the effect of beliefs. For example student S462 said “There will always be, like bias, like biased scientists, but I mean, I think that's why, that's the importance to have more than one person doing something.” Another method for ensuring beliefs did not distort findings was suggested by student S292 who identified the risk to reputation as a major concern for scientists. This student suggested that if belief biased a scientists finding and they were found to be wrong, the repercussions would be detrimental, “There is always the repercussion … after you did something like that, effectively, your career is ruined.”

As with the previous category, these students still felt beliefs needed to be controlled but identified external measures as the key. The presence of other scientists was seen as vital in enforcing this control.

> *If someone believed in it so much they have more than one person working on it so if it isn't the right answers, then the others kind of like... so the beliefs might have got in the way at first, but if there's more than one person working on it, then it would be the right answer then. (S202)*

Beliefs affect choice

Seven students from across all three sample groups associated beliefs with affecting the choices scientists made. For example student S093 said “Your opinion bases what you want to find out. Like, if you believe in this then you're going to go off and try and find something about this particular way.” As with the previous categories, these students expected scientists to disentangle beliefs from facts. For example student S377 explained “it also depends on the scientists themselves, whether they can separate their beliefs from, like, if they find actual fact in science.” However these students suggested that the beliefs scientists held would affect the research choices they made. For example student S355 suggested,

> *I suppose you can't be 100% sure with science ever, so, they, yeah. I think it would affect maybe what area of science you go into. So maybe if you did believe in creation you wouldn't really look into evolution too much. (S355)*

Student S279 agreed that the scientists would make a choice, "'cause I am Christian, um, I believe the scientist has to make the choice of which one to choose."

Beliefs were also perceived to be involved in motivation. Student S468 noted, "It might give you incentive to research something" and student S469 said "Sometimes if you believe in something it might make you want to prove or want to, like stick to a certain theory." While beliefs were perceived by these students to affect choices it was not expected to influence the results. As student S093 explained when asked what would happen if scientists had different beliefs about an issue, "If there's facts to back up both then obviously either one of them's lying or something went wrong there."

11.4.2.3. Summary

The students viewed imagination and beliefs as traits that scientists needed to be able to control. Imagination was seen as a beneficial and important trait for scientists when generating new ideas. However the students believed it was unnecessary after the data had been collected as the experiment, done correctly, would produce clear results. If the results were not clear students' thought imagination would be used to try to identify what was stopping the experiment from producing clear results. Imagination was also seen as important for the generation of new inventions and applications.

Students also thought that beliefs were something scientists needed to keep in control. The students noted two ways for controlling beliefs and one way in which it would influence scientists' pursuits. The first way students thought beliefs could be controlled was through the actions of the individual scientists. These students believed that a scientist could ignore their beliefs when presented with the clear facts produced by experiments. The second way students thought beliefs could be controlled was through the actions of scientists collectively. These students viewed beliefs as something that could cloud a scientist's interpretation of experimental results. As such these students suggested that the repeatability of results and peer review were important safeguards against belief influenced mistakes and fraud. The final category of students viewed beliefs as the thing that would affect what scientists studied. These students thought that scientists with faith beliefs would stay away from subjects where their beliefs would be challenged. For example, they did not think a scientist with beliefs in creationism would choose to study evolution.

In responding to these questions all the students thought that imagination and belief were things that scientists would need to control. The students believed that uncontrolled imagination or beliefs would distort or obscure the facts that the scientists' experimental work uncovered.

11.4.3. What do the terms scientific law and scientific theory mean?

All the students were asked to describe what they believed the terms scientific law and scientific theory meant and to explain what they thought the relationship between the two terms was. The question had been included to help identify substantive reasons as to why the questionnaire items relating to these two terms had been so unreliable. Four categories of responses emerged from the interview data analysis (see Table 11.7). The students in the first category identified a hierarchical relationship between the two with law being a proven theory, (e.g., "If your theory was proven unchangeable … sort of unbreakable I guess it would become a law" (S024). One student, placed in the second category viewed the two terms as an equivalent relationship with law and theory seen as equal, (e.g., "Like side by side" (S089). Two students gave unique views about the relationship and were placed together in the third 'other' category. One student viewed theory as general and law as specific and one viewed law as the boundary of what could and couldn't be done with theory as the testing ground of that boundary, (e.g., "Theory is going from, from the scientific law, it's taking the rules that you can't break and going, well what if, what if I could break it?" (S021). The students in the last category were uncertain what each term meant (e.g., "I haven't heard it" (S279).

Table 11.7

Coding categories for relationship between law and theory

		Coding category			
Group	Student	Hierarchy; theory becomes law	Equivalent concepts	Other	Uncertain
Group 1	S021			x	
	S033	x			
	S105			x	
	S112	x			
	S292	x			
	S355	x			
Group 2	S024	x			
	S081	x			
	S085	x			
	S089		x		
	S093	x			
	S154	x			
	S202				x
	S377	x			
	S462	x			
	S468	x			
	S469	x			
Group 3	S054	x			
	S279				x
	S289	x			
	S378	x			
	S410	x			

Hierarchy; theory becomes law

Seventeen students from all three groups identified the relationship between scientific law and theory as hierarchical with theory seen as subordinate to law. For example student S292 described theories as "The lower one is probably theory because, it's an idea … there mightn't be enough solid evidence to establish the truth behind it". These students placed law as the superior concept as they associated law with a rule or fact about the way the world works. For example student S085 explained that laws are “A rule that applies to everything” student S112 described them as “The rules that they use to explain things … rules that can't be changed.” Students also associated laws with physics and calculations, “laws of physics, motion, those kind of things” (S289).

While most students associated laws with absolute knowledge, “they’re fact, set in concrete” (S289), five students recognized and tried to account for uncertainty. For example student S378 noted that “I guess they can't really be fact, but all of the evidence that you've, that you've collected points to that thing and none of the other.” These students associated this uncertainty with our limited knowledge, “laws are as solid as we can get with our current understanding” (S462) and viewed the length of time a law existed as a measure of its certainty,

> *They’re not absolute laws … they are what just happens to fit for what we know at the time. Isaac Newton's laws are still around so obviously they must be pretty right because nobody's managed to disprove them … it's like, you do this, this will definitely happen. (S292)*

The students noted that laws would be refined over time as improved technology and resources allowed more accurate experiments to be conducted. For instance student S468 explained that “over time and they have more resources they realise new things … [but] it wouldn’t be completely changed because the root of it would still be the same”.

The students in this category viewed theory as an idea or thought that lacked proof. Student S033 described theory as “something that's not proven yet” and student S377 explained that “It's not necessarily true, it's ... more of an opinion than fact at the beginning stage until it goes through processes of testing it and experimenting and proving.” The students equated proving a theory with a transition into law. Student S112 explained that if proven a theory would “Um, probably become a law. And if it doesn't work, then it will still be a theory … a bad one if it doesn't work” (S154). This hierarchical process was understood to involve proving of theory via experiment so it would become a law, “Theory is the primordial stages of a law … [it] has to go through a series of tests and like experimentation to make it more solid" (S462).

This view of theory was often associated with evolution. Students either suggested this example themselves or when presented with examples of theories for clarification, such as evolution, atomic or quantum theories, gravitated to the first example as being the one they were most aware of. Their perception of evolution was that it lacked sufficient evidence.

> *I think it's something that, it's like true but it hasn't been, it's not quite like, like not everyone believes it. Just sort of, most people believe it and most facts would point to it being true, but then it's not definite, so it's not a law. (S410)*

This seemed to act as the students' guide for what the term theory meant and they would rationalize the same doubt when asked to compare evolutionary theory to atomic theory, "The thing with atom theory is that it might not be the same somewhere else. The same with evolution theory. So I think, I think there's a very big grey area on how certain theories are" (S292).

Law and theory as equivalent

Student S089 gave the closest explanation to the accepted meanings of law and theory identifying the two as equivalent. While the student described law in a similar fashion to the other students, "formulas to how everything works … I guess they've been like proven", theories were instead linked to explanations, "people's way of trying to explain things using, like, logic". Student S089 then uniquely identified the two terms as being equal, "I think they're like quite equal sort of." This identification of the two terms as being equivalent was unique but the student was unable to elaborate about what this meant and it was inconsistent with their questionnaire responses which indicated that they agreed that theories would become laws.

Other descriptions

Two students from group one each described unique relationships between law and theory. Student S105 viewed theory as global idea and law as specific instance, “Theory can be quite a, like a significant thing, like it can be anything. But I think law kind of is easier because you think well, how would I do something.” This interpretation seemed to be based on the student’s association of law with formulas and calculations, “they use kind of like that formula, to figure out other things” and theory with wider explanations, “how they think things have come around to be.”

Student S021 identified the relationship between law and theory as a boundary, with law setting out what could and couldn’t be done and theory acting as the space where that was challenged. Student S021 viewed scientific law as set facts, “like it's a fact that there's 3 solid states” but also saw laws as defining the boundary between what was and wasn’t possible. This boundary was then motivation for people to challenge the current boundaries and find ways to make the seemingly impossible possible.

> *When I think of scientific law ... you know how they say that rules are made to be broken … I think scientific law is kind of made to be broken. That back when it made it was like, “oh, you can't do this, you can't do that” … but then because they made scientific law, people went, "I want to challenge that." … Then they found so many new things and ways to do things and then that just made the scientific law bigger. (S021)*

The student further defined this view of science with an illustration showing that scientific law defined the boundaries of current knowledge and theories acted as the space were current boundaries were pushed and tested (see Figure 11.2). “There's like, kind of 3 rings of it. It's like kind of, the can't, the can, and the ones that say both.”

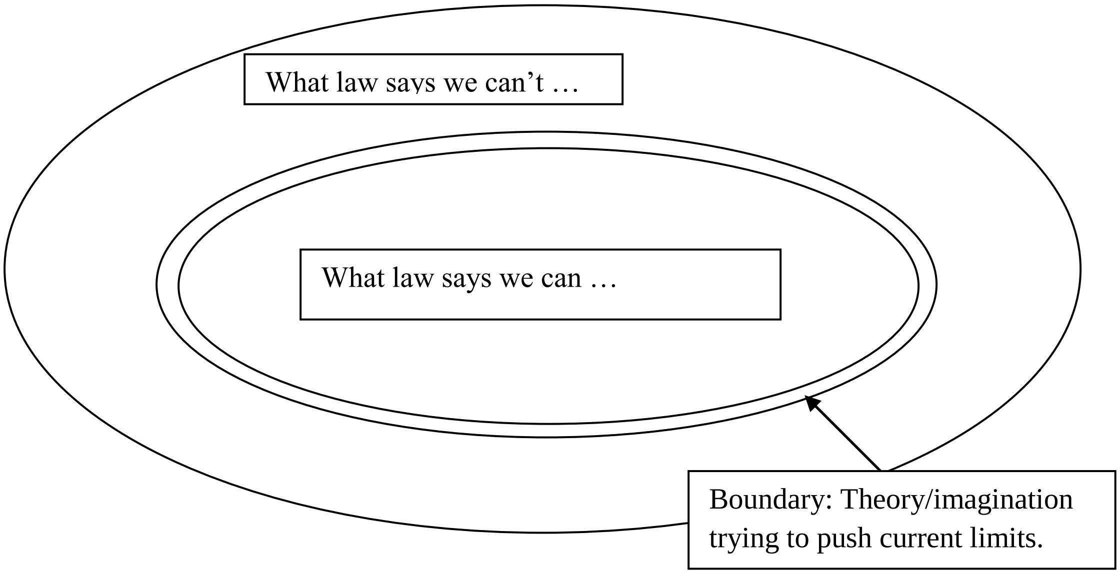

Figure 11.2. Adapted from the drawing by student S021

In describing the diagram, student S021 emphasised how imagination interacted with law to define established knowledge and new research, "what we can't do, what we can do, and what could be possible. It's the fact is, you can't do this, and the imagination goes, but what if I could?" Theory was linked to the imaginative act of pushing back the current boundary, "taking the rules that you can't break and going, 'well what if I could break it?' Then trying to figure out a way to break it, that's kind of what theory is." This view was entirely unique during the interviews and showed the efforts the student had gone to establish a personal framework through which to interpret new scientific information.

Uncertainty about the terms

The two remaining students were placed in the uncertainty category. While both students attempted to define the terms they did so after stating they were unfamiliar with the terms, "I haven't heard it" (S279). When the students attempted definitions, both associated law with behavioural rules, "Is that rules with other, um, scientists. Like don't steal other people's ideas and stuff?"(S279). When asked about theory student S202 associated it with hypothesis "what they kind of think is going to happen?" and S279 with the writing side of practical work, “like doing explanations and stuff instead of doing a practical.”

11.4.3.1. Summary

The majority of students in all three groups viewed law and theory in a hierarchical way. Of the five students who did not fall into this category, only student S089 indicated that they thought the two term terms were equivalent, though this was not reflected in their questionnaire responses or their definition of law. For twenty of the students, law was seen as a proven or factual part of scientific knowledge. Students also repeatedly described a process whereby theory, either informed or guessed, was transformed into proven law through experiments and the collection of evidence.

These results showed that students lacked acceptable definitions of what law and theory meant and associated the two terms with the start and end of scientific investigation. The students’ responses to these terms seem to be based on their previous experience. When asked about law, students often replied with a reference to physics associating laws with formulas that were seen as proven because they could calculate what would happen. By comparison theory was most often associated with evolution and unproven scientific ideas. Students saw theory as being in doubt because of a lack of consensus that they associated with insufficient evidence. While the link between perception of evolution and the definition of theory was not explicitly examined in this study the data gathered appears to support this assertion.

In the absence of clear definitions of what the terms scientific law and scientific theory mean, students appear to have used their prior knowledge and experience to generate definitions of the two terms. From this, law is associated with proven factual knowledge and theory with unproven ideas. The majority of students from all three sample groups held the misconception that a theory would become a law when it was proven as a fact through a definitive experiment.

11.4.4. What does the term scientific method mean?

All the students were asked to describe what they believed the term scientific method meant. This section of the interview was intended to identify students' understanding of the term used in the questionnaire. Four categories of responses emerged from the interview data analysis (see Table 11.8). The students in the first category associated the term scientific method with the steps involved in an experiment, (e.g., "the method is a way of doing it … say, to boil something" S021). The students in the second category associated the term with a process of investigation, (e.g., "looking at a situation, thinking about why it happened, gathering evidence, making experiments, and drawing conclusions from that" S081). The students in the third category, defined as other, included two students with unique views. One student associated scientific method with the actions of scientists and the second with the application of science. The students in the final category were defined as uncertain and included two students who responded that they were not familiar with the term, (e.g., "No, I haven't heard that one" S105).

Table 11.8

Coding categories for student definitions of scientific method

		Coding category			
Group	Student	Steps in a method	Process of investigation	Other	Uncertain
Group 1	S021	x			
	S033	x			
	S105				x
	S112	x			
	S292	x			
	S355	x			
Group 2	S024	x			
	S081		x		
	S085			x	
	S089			x	
	S093	x			
	S154	x			
	S202	x			
	S377	x			
	S462		x		
	S468	x			
	S469		x		
Group 3	S054	x			
	S279				x
	S289	x			
	S378	x			
	S410		x		

Steps in a method

Fourteen of the students from across all three groups described the scientific method as the steps involved in an experiment. For example student S355 said it is "how you do something. The steps to doing something, like experiments and stuff" and S024 identified it as, "a way of doing something or like a step towards doing something … stepping stones towards the experiment." Student S292 suggested that the term scientific method was possibly a larger concept, "There's probably a lot more to it", but in the end could only suggest that it would involve thinking about setting up the experiment and organising the data. “Before you do something, you’ve got to think about it [and] do this, this, this before you do an experiment … you must [have] tables to record, that kind of thing”. The aim of the scientific method was seen to be to prove your idea, “the steps you go through to prove something” (S378).

While students agreed that there were many different ways that the scientific method could be used, “there's different methods to find everything” (S093), they were referring to the different methods found in different experiments. Student S093 explained that “to find if there's oxygen or carbon dioxide in this gas, you follow the method and this happens” and student S054 noted “If you'd want to prove something for light, you wouldn't apply to something you'd prove with water”.

A process of investigation

Four students from sample groups two and three were coded in this category. These students gave descriptions that outlined the scientific method as a process that involved such things as identifying the problem, working out ways to solve it, collecting data and drawing conclusions. Student S410 described it as, “sort of processes to find stuff out … a basic structure that you, ask the question and then you research what has already been researched and then you work from there”.

The students did not present consistent views of what the process involved and each focussed on different aspects as being important. For example student S081 identified the outliers of experiments as being important for leading to new discoveries, noting “it should be explainable … because it could lead to discovery of new ideas”, whereas student S462 emphasised the need for repeatability, “The most important part of the scientific method, is that it's repeatable”.

As with the steps definition given by most students, the process was still associated with the idea that it allowed you to prove your idea. Student S462 associated the scientific method with something that was done “so you can prove that you're right”. The students with a process view of science also made the connection that the data gathering process would need to be different. Student S469 explained that “Depending on what you're studying, it probably means you have to change the way you go about getting the information”. This student also recognised that what was being studied impacted on how you collected data, “sometimes it’s not that straightforward to go and collect stuff” (S469).

Other definitions

Two students from sample group two had unique descriptions of what scientific method meant. Student S085 focussed on the actions of scientists and their need to need to be impartial. The scientific method was “The way that scientists kind of treat theories and experiments, like they're meant to be impartial about it and things”. Student S089 viewed the scientific method as the application of science towards generating new products, “How people use theories and laws … like how we have cars today … applying theory and law.” Both these definitions touched on aspects of the perceived wider process of science, but the students did not appear to recognise how the scientific method was used to generate and validate scientific knowledge.

Uncertainty about the term

The two remaining students were uncertain about the term. Neither student was familiar with the term, “I have no idea” (S279), though student S105 wondered if it had something to do with data collection, “um … it could be how scientists, get information or something” (S105).

11.4.4.1. Summary

The students’ responses indicated that they were not familiar with the term scientific method. Fourteen students associated the term with the method steps of an experiment but most noted they were unsure about their answer. Only one student in this category explicitly recognised the term but noted it was due to a computer game, “Yes, I've heard of that. I've played Civilization ... that's one of the researches” (S054). The association of the term scientific method with the methods section of an experiment appeared to derive from it being the only place students had encountered the term method during their science lessons.

The four students who associated scientific method with a process each outlined slightly different aspects as being important. The different emphases that the students applied indicated that they too were uncertain about the term and were generating a meaning based on their personal experience. While these students did appear to have a better perception of what the scientific method involved, they still appeared to lack explicit knowledge of the term and as a result had formed varied interpretations of its meaning.

The two students who defined the scientific method in terms of the actions of scientists and the application of science towards producing new products also showed a lack of explicit knowledge about the term. Like the students in the previous two categories they appeared to have generated their understanding of the term based on their personal experience rather than on any explicit explanation of what the scientific method referred to. The remaining two students expressly stated their uncertainty about the term again indicating that the students involved in the study had had no explicit instruction about what the term meant.

11.4.5. Student responses to non loading questionnaire items

Students were asked about their interpretation of the five items that failed to load to the four-factor model in the initial EFA and subsequent CFA testing. Not all the students were asked every question due to time constraints. A summary of the response categories and a substantive interpretation of the associated questionnaire responses are given below.

11.4.5.1. Social item two: 'scientific data can be interpreted in many different ways'

For social item two, three categories of responses emerged from the interview data analysis. The four students in the first category viewed varied interpretations as being possible if the evidence collected had multiple applications. For example student S021 explained that "the person who made the test doesn't realize it, they could actually explain something else by the test … so this is how grass works, and then another one comes along and goes that's also how leaves work." Alternatively the data could also be presented in different ways as student S355 noted, "like a line graph or like a pie graph, you can look at it different ways kind of in the positives and the negatives of what's happening." Students in this category associated different interpretations with distinct valid conclusions rather than competing ones and so tended to agree with the statement.

The seven students in the second category of responses identified beliefs as causing differences in interpretation. For example students S377 said “I suppose like the evidence of it, some people could still believe it and some people could not.” This situation was associated with lack of evidence that could be overcome, “If you had enough evidence to prove one theory, and enough of the other people that didn't believe that could see that it was true” (S378). It was also linked to the beliefs discussion that multiple scientists would work on identifying the correct answer, “that's why different people, ah, do it, ah, test it.” The students in this category agreed with the statement if they interpreted the statement as referring to the data prior to peer review taking place, “for some people it could be interpreted different ways” (S093), but disagreed if they thought it referred to the final proven answer, “but usually it's just one specific way that you can interpret it” (S378).

The four students in the final category saw the different interpretations as being the result of methodology issues. For example student S154 said “People could interpret it like, that that's not how it should be done … they could have different interpretations of how it's done.” These students agreed with the statement as they associated different interpretations with different beliefs about how the phenomenon should be studied, “One person may think of it in this way, and then another person may come and say, "Oh, wait, but there's another” (S105).

While the questionnaire responses to social item two suggested students were aware that varied interpretations of phenomena could exist, the interview responses were not consistent as to what this meant. It was clear from the interviews that these students believed that the ‘correct’ answer would be achieved when the right experiment was conducted. This was consistent with the view of science that was described in the previous sections.

11.4.5.2. Social item six: ‘past explanations do not affect new scientific explanations’

For social item six, two categories of responses emerged from the interview data analysis. The seven students in the first category agreed with the statement and saw past explanations as being irrelevant if new data or explanations superseded them. For example students S021 said “If they do prove it wrong, you can't go, yeah, but back here they said you couldn't.” These students viewed only the updated and improved explanation as relevant, “Past explanations that didn't prove anything could have been put, like away, and then new ones that worked” (S154). The replacement of the old explanations was associated with new advancements in technology and new evidence, “they didn't have so much technology back then and there'd be new technology, so they'd be able to prove it, or change it” (S378). The students in this category saw no need to go back to past explanations if newer data existed, “I wouldn't really understand why they would look back at older experiments” S054 and so most agreed with the statement. However some students with this interpretation disagreed with the statement as they noted that the past explanations were likely to have been used to define other work that would now also need to be revised, “the past will come back to haunt you” (S033).

The eleven students in the second category disagreed with the statement, believing that past explanations would shape future explanations by defining and constraining what was investigated. For example student S085 noted,

> *Like when Charles Darwin was wanting to come out about, you know, natural selection and all that. Um, he didn't want to do it, he, I think he kind of watered it down almost kind of thing, cause he, you know, and he didn't put in, you know, about mankind. (S085)*

Two students also defined the constraints in terms of social or scientific acceptance noting that new evidence would be cautiously used if it contradicted established ideas, “Like if you discover something, but you sort of doubt yourself because like, of what someone in the past said, someone like more famous” (S089). The other students associated past explanations with defining future research paths. For example student S377 said, “I think they would affect them because to get new scientific theories they're based on what they know, and they know things from past explanations and theories.” The students in this category all disagreed with the statement as they saw the past explanation as either constraining what was investigated or was fundamental to what was built upon by new evidence and technology.

11.4.5.3. Scientific Method item two: 'there is no single scientific method'; Scientific Method item five: 'the scientific method refers to the steps all scientific experiments follow'

As the term scientific method was examined specifically in the interviews (see section 11.4.4) these two items were only reviewed with students to confirm the way the term scientific method was used to interpret the items. Students with a 'steps' definition agreed with item two associating this statement with the steps of multiple experiments, "There are lots of different ways to test for something" (S021). Students with a 'process' definition agreed with the item as they recognised different data collection methods would be needed, "If you can't get evidence, well, can't do experiments to get evidence, then you just have to collect evidence without doing the experiments," (S081).

For item five the students with a 'steps' definition disagreed with the items as they viewed each experiment as having different steps associated with their methods, "they wouldn't follow the exact same steps because each experiment is different," (S377). The students with a 'process' definition disagreed as they recognised different situations affected the way research could be conducted, "You have to adapt it to whatever you're answering" S410. The responses to the questions about these items confirmed that while some students were making truly informed responses many of the students were producing false positive results by using an inappropriate definition of the term scientific method. The combined interview data indicated that the items that referred to the term 'scientific method' were not reliable due to students being uncertain about the terms meaning.

11.4.5.4. Empirical item one: 'scientific evidence only includes data from the world around us

For empirical item one, two categories of responses emerged from the interview data analysis. The first category was students who agreed with the statement and identified the term 'world around us' as intended. For example student S081 said "it's like from earth and around the universe." The second category of students disagreed with the statement as they interpreted 'world around us' as being limited to earth and near-by objects. For example student S289 identified that there were "facts outside of this world, like Mars is red." The failure of the term 'world around us' to be consistently interpreted by students meant many students selected a naïve response despite using an informed belief about empirical evidence to reasoning out their response choice. The interview data provides sufficient evidence to justify excluding the item. As student S292 noted "it was one of those questions where you don't define what the 'world around us' is."

11.4.5.5. Student S033

Student S033 responded to 32 of the 35 items with the extreme case responses of one or nine. For this reason, this high scoring student was instead asked about the three items that they did not respond to in this way. When queried about their neutral response to tentative item four, 'the study of science finds out the absolute truth about the world around us' the student explained that while some things could be answered with certainty, "the stuff that you can actually see, like this is a table and stuff" not all facts were beyond doubt, "you can't prove that, like, well the centre of the earth or something. That's just a theory." The student appeared to select the neutral option as they identified some knowledge as being absolute and some as being open to conjecture or unproven.

When the student was asked about scientific method item four, "professional scientific experiments produce exact results" they noted that in any experiment tiny fluctuations limited accuracy, "They can't be completely exact. Because there's always microscopic, I guess, things that can turn it off." This concept appeared to be at odds with the students' view that certainty could exist about answers and so resulted in the student selecting a neutral response. Like the other students S033 was also asked about empirical item one and like many of the students noted that empirical evidence "can come from anywhere, not just the world around us."

11.4.6. What has influenced your beliefs about science?

The researcher asked all the students about what influenced their beliefs about science. Four categories of responses emerged from the interview data analysis and students were categorised according to the dominant influence they described (see Table 11.9). The students in the first category identified school and teachers as the dominant influence on their beliefs about science, (e.g., "I think schools a big one" S089). The students in the second category identified family beliefs as a dominant influence on their beliefs about science, (e.g., “I've got a father which is really pro-science. My mother as well.” S054). The students in the third category identified educational resources as a dominant influence on their beliefs about science, (e.g., “like channels on TV that are like, above 70, some of them have some things on science.” S202). The students in the final category identified multiple sources as having influenced their beliefs about science, (e.g., “ I don't think anything in particular has covered the whole of science for me but I guess schooling would have to be the main thing, maybe some books, like books about space … TV programs and websites and I guess” S024).

Table 11.9

Coding categories for what has influenced students' beliefs about science

Group	Student	Coding category			
		School	Family beliefs	Educational resources	Multiple sources
Group 1	S021				x
	S033				x
	S105		x		
	S112	x			
	S292		x		
	S355	x			
Group 2	S024				x
	S081	x			
	S085		x		
	S089	x			
	S093	x			
	S154	x			
	S202			x	
	S377	x			
	S462				x
	S468				x
	S469	x			
Group 3	S054		x		
	S279		x		
	S289			x	
	S378	x			
	S410	x			

Influence of school

Ten students from across all three sample groups identified school as a dominant influence in shaping their beliefs about science. For example student S093 said "obviously school would be a big part of that." The actions of teachers in class were noted as a significant factor in shaping students' views of what science was doing. For example student S154 explained that teachers "sort of say what's supposed to happen and you do that, experiments and stuff. And then you just go by what they say and then, or prove it."

The students at college four, who had experienced the NOS course prior to the study, noted that concepts such as falsifiability were unique to school. For example student S377 said “I guess I thought it was more proving something to be right rather than proving something to be wrong,” and identified school as being the source in this change in thinking, “I don’t do much science things out of school.”

Influence of family beliefs

Five students from across all three groups identified their family’s beliefs as having affected their view of science. The beliefs could be secular, “I just find science more attractive than things which involve religions because I've been raised like that” (S054), or religious, “‘cause I'm a Christian and stuff like that, so, yeah, that's one of the things that, um, have influenced me the most” (S105). Family beliefs that agreed with science created an atmosphere that encouraged science at home. For example student S085 whose mother worked for a publishing company would “bring home books about science and things.” In both the secular situations the students identified science as their desired future career, “I'm personally quite interested in science, I want to do it in the future” (S089).

The students with a religious background found science to be more problematic. As student S292 explained;

> *I think also the family upbringing as a Catholic's also taught that you know, um, you've got told there is a definite tolerance [sic] that you've got to hold between science and religion because science, you know, really goes hand in hand with atheism. (S292)*

This student also noted that they had never formed an interest in science and school had not improved that, “school has really done very little to spark an interest in science and unfortunately that's just the way that some things work” (S292).

Student S105 also experienced conflict but explained that “I think that the religion sometimes explains some of the science that we don't actually know about.” This student also noted that when scientific ideas clashed with religious ones then they would look at the evidence, "like I'll question it. And then if the evidence seems to be true, then maybe I'll believe it." Student S279 experienced the same issue, "it's pretty hard, because especially, 'cause my dad's a minister" but noted that they enjoyed science as "I still want to search more and more about science 'cause yeah, having this belief in me I don't know what this side of the story is." This desire to learn appeared to be stimulated by the student's parents who, despite their religious belief, were keen to encourage discussion at home about science, "they're open, yeah. They talk to me about science."

Influence of educational resources

Two students identified educational resources as the primary influences on their beliefs about science. Student S202 identified the documentary channels and student S289 identified 'Mythbusters' in particular as an influences in their beliefs about science. For example student S202 noted that even though they were "not very good at science" the information on some of the shows "helped change my point-of-view of scientists."

Multiple influences

Five students from groups one and two identified multiple sources as having shaped their views of science. These students identified their personal desire to learn as having been a factor in the development of their beliefs about science. For example, student S033 explained that he read a lot of physics books because "I wanted to learn more … It just interests me." The students identified their teachers as helping shape their view of science. For example students S021 described how "just having him, talking to him about science things really kind of helped me understand science quite a lot more". They also identified educational resources as contributing to their views of science. For example, through books and documentaries the views of great scientists influenced student S462's ideas about what science is,

> *I still have like very little understanding now, but I mean before when I knew absolutely nothing, I would look to great scientists like Hawking and*

Sagan and stuff and then I'd try to adapt my own personal interpretation of it from what they believe it is. (S462)

Notably the students in this category did not identify family as being an influence on their beliefs. The only student to mention family did so in response to a question about other family members being interested in science and noted how different they were from the rest of their family, “They’re more into arts and movies and stuff” (S033).

11.4.6.1. Summary

The students interviewed identified school and teachers, educational resources, their families and personal traits as factors that shaped their beliefs about science. Most of the students identified school as either the primary source influence on their views of science or as an additional influence. The influence for most students appeared to be implicit and based on the way experiments were set in class. Notably the students in the multiple influences category identified discussing NOS like concepts with their teachers outside of normal lessons as a more important contributing factor than any activities conducted in normal lessons.

Students, except for those in the multiple influences category, identified family beliefs as affecting their beliefs about science. Students with a secular background appeared to place significant faith in the certainty of scientific explanations. Those with religious backgrounds tended to be more cautious of scientific explanations especially in areas where they were perceived to conflict with their religious beliefs

External educational resources such as documentaries and books were also identified as being an influence. However students were certain that fictional sources were not affecting their views of science. Only student S279 made a reference to fictional views of science when describing the traits of science (see section 11.4.2.1.).

Personal traits also appeared to influence the way students saw science. Those in the multiple influences category identified their ideas about science with the traits they believed made them good future scientists. This was seen as a prompt for them to learn more and to pursue multiple sources to help build their understanding of science.

11.5. The Emergent Themes of Students' NOS Beliefs

During the interviews two key themes emerged as being critical in shaping the students' interpretations of what is science. These themes crossed all three sample groups and were touched upon by students responding in each of the coding categories. The first and most important idea was students' consistent reference to 'fact' as the ultimate goal of science. All students saw facts as being the ultimate outcome of scientific research. These facts were considered to be absolute, faithful replications of reality and were deemed to be free of human beliefs or perception. While some students described laws as synonymous with facts others did identify that some discrepancy existed. However in these cases the limitation was seen as the limits of current technology and that eventually the absolute fact would be ascertained.

From the misconception that facts were the pinnacle of the scientific pursuit emerged the idea that scientists set out to prove their theories. In this pursuit the scientific method in the form of experiments was seen as the tool that allowed scientists to remove the influence of belief, either through self discipline, repetition or the influence of peers. The ultimate goal of the experiment was to test the unproven theory and to transform it in to a proven fact. These two prominent themes appeared to be the dominant concepts that guide the students' interpretation of the questionnaire items and their understanding of science. For all the students interviewed, proven fact was perceived as the ultimate goal of science. This was seen by students to be supported by what they did in school, as student S202 noted "because they're teaching us it that it must all be the truth if they take it. Cause they would go over it heaps of times before they let out the information about it."

These two emergent themes appear to play a dominant role in the way students understand science and match the suggested construct themes of purpose and process identified in the quantitative analysis. In the following section these two correlating pieces of evidence will be examined further as the qualitative and quantitative results are analysed. Specifically the researcher set out to develop an enriched understanding of why specific items failed and to identify areas of symmetry between the constructs identified by the questionnaire and the descriptions of science given by the students.

CHAPTER 12 – MIXED ANALYSIS

Overview

According to Bergman (2010), both quantitative and qualitative research methods can be used where the researcher is investigating the variations in the constructed meaning of concepts. In such cases both quantitative and qualitative data collectively enrich the research (Bergman, 2010; Onwuegbuzie & Combs, 2011), provided the researcher confines the research interpretations within objective limits consistent with theoretical underpinnings and the collected data (Yardley & Bishop, 2008).

Utilizing mixed analysis recommendations (see section 3.4.5) the researcher compared the students' descriptions of NOS with those referenced in educational literature. Using the underlying constructivist theoretical lens that students construct their understanding of NOS based on their experience and prior knowledge, this study aimed to use quantitative and qualitative data to identify the key student ideas that shaped their beliefs about NOS. That is, this study aimed to use the quantitative and qualitative data to identify and describe students' NOS positions and beliefs.

The quantitative data consisted of the questionnaire responses. I utilized previous research on NOS to develop a multidimensional model of NOS. It was assumed that the students' responses to each item would be derived from their beliefs and understanding of each NOS tenet (see section 2.4). The data analysis of the items revealed this was not the case. While some items had substantive identifiable reasons for exclusion, which the interviews supported, the failure of the tenet items to correlate was not immediately obvious. Therefore, I explored other possible factor solutions to find whether items correlated better with an alternative structure. This lead to the selection of a four-factor model that consisted of different constructs from the one proposed (see section 10.5). This factor solution was used to select students to interview.

The qualitative data provided by the interviews provided rich descriptions about students' understanding of key aspects of science. This data helped to 1) provide substantive reasons for the exclusion of several items from the questionnaire and 2) helped to explain the origin of the different interpretations that the students who were interviewed had about the items. Ultimately, students in all of the groups described science being used to prove absolute objective facts.

During the interviews students identified three key goals for science, 1) provide explanations, 2) identify new discoveries and 3) generate new knowledge. The students identified science as being able to explain material things but not necessarily human activities and actions. They saw science being able to prove its claims as a key underlying principle that meant it was exclusively about facts with no room for opinions or different interpretations. School science was seen to exemplify this in that students expected to encounter only proven facts in their textbooks and lessons (see section 11.4.1).

Imagination and beliefs were traits the students believed scientists needed to control. They believed that imagination and beliefs would: 1) affect what a scientist studied, i.e., a believer in Genesis would not study evolution, or 2) that these would distort and obscure the facts that the experimental work had uncovered (see section 11.4.2).

The majority of students in all three groups viewed law and theory as hierarchical. Of the students who did not espouse this idea, only one student (S089) indicated that they thought the two terms were equivalent, though this was not reflected in their questionnaire responses or their definition of law. Twenty of the students saw law as a proven or factual part of scientific knowledge. Students repeatedly described a process whereby theory, either informed or guessed, was transformed into proven law through experiments and the collection of evidence (see section 11.4.3).

These results showed that students lacked acceptable definitions of what law and theory meant and associated the two terms with the start and end of scientific investigation. The students' responses to these terms seem to be based on their previous experience. When asked about law, students often replied with a reference to physics, associating laws with formulas that were seen as proven because they could calculate what would happen. By comparison, theory was most often associated with evolution and unproven scientific ideas. Students saw theory as being something in doubt because of a lack of consensus which students associated with insufficient evidence. While the link between perception of evolution and the definition of theory was not explicitly examined in this study, the data gathered appears to support this assertion. In the absence of clear definitions of what the terms scientific law and scientific theory meant, students used their prior knowledge and experience to generate definitions of the two terms. Law was associated with proven factual knowledge and theory with unproven ideas. The majority of students from all three sample groups held the misconception that a theory would become a factual law when it was proven by the right experiment.

In this section, the results gained from these two data sources are analysed together to identify the areas of symmetry and conflict. First, the quantitative data of the non-loading items are examined alongside the interview data to identify substantive explanations for the students' response choices and to explain why the items failed to load. Second, the data driven quantitative constructs are examined alongside the interview data to search for symmetry to support the appropriateness of the factor solution and to identify why the expected theoretical NOS tenets did not emerge.

12.1. Non-loading items

The CFA data indicated that a four-factor solution generated the most parsimonious fit for the questionnaire response data. However, six of the intended items failed to load to this solution. To substantiate why the items could be justifiably excluded, participants who were interviewed were asked directly about the items to collect complementary data to justify the exclusion of the items (Onwuegbuzie & Combs, 2010). As noted in sections 10.6 and 11.2, due to time constraints, only some students were questioned about the items, and only five of the items were addressed during the interviews.

12.1.1. Social item two

Social item two, 'scientific data can be interpreted in many different ways,' (M = 6.65, SD = 1.43), did not load to any of the constructs. During the interviews, it became clear that the students had three distinct ways of interpreting the statement. First, students who disagreed with the statement thought the 'right' experiment had been completed and so definitive proof now existed that did not require interpretation. This interpretation was a clear example of naive realist beliefs. Second, some of the students who agreed with the statement saw it as a superficial difference, i.e., data could be displayed in different formats (e.g., line graph or bar chart) or utilised in different fields (e.g., photosynthesis could be applied to grass or leaves). Third, some of the students who agreed with the item indicated that it meant scientists had yet to develop the 'right' experiment needed to answer the question definitively. All of these responses reflect naive realist beliefs about the absoluteness of scientific data. The item failed to load as the students interpreted the statement differently even though they espoused the same naive realist beliefs in the interviews.

While the questionnaire analysis was able to detect that the item was faulty, it was not able to detect that it was due to pseudo informed responses. Only when the interview data were examined holistically did it become clear that naïve realist beliefs were producing the informed responses. This item was a poor discriminator of beliefs about the need to interpret scientific data; however, the interview data helped clarify why this item did not load, namely that the students taking part in this study held naive realist beliefs about NOS.

12.1.2. Social item six

Social item six, 'past explanations do not affect new scientific explanations,' (M = 5.76, SD = 1.91), did not load to any of the constructs. During the interviews it became clear that two categories of responses were associated with the item. The students in the first category espoused a recognisably naive realist belief stating that the past explanation was irrelevant if a new explanation had been proven. However, some of the students in this category rationalised an informed response. They noted that the old 'incorrect' explanation would have been used in other work which would now have to be reviewed and corrected. These students still held a naive realist view of science but espoused an informed position via an unexpected rationalisation.

The students in the second category selected an informed response by reasoning that past explanations would play a role in what data was collected. Some students also recognised that the new explanation could be treated cautiously if an existing idea was well established. While these responses were consistent with informed views of NOS, in the interviews it became clear that a naïve realist belief also defined this interpretation. The students downplayed the role that a new interpretation of old data could play and instead viewed the new explanation as the result of better technology or a better experiment. The students still viewed experimental data as absolute, outside and independent of human reason and interpretation.

The item failed to load as while the questionnaire detected different categories of responses, the interviews revealed the students all held naive realist beliefs. The item was unable to detect this and instead generated false informed responses due to the way the students interpreted the item. Ultimately in identifying a substantive reason to exclude the item, it helped support the conclusion that the students taking part in this study held naive realist beliefs about NOS.

12.1.3. Scientific method items

Scientific method item two, 'there is no single scientific method,' (M = 6.69, SD = 1.90) and scientific method item five, 'the scientific method refers to the steps all scientific experiments follow,' (M = 4.66, SD = 1.60), both items failed to load to any construct. During the interviews it became apparent that students did not have explicit knowledge of what the term 'scientific method' referred to. In the absence of a common explicit definition, students interpreted the term as either referring to: 1) the procedural steps of an experiment, or 2) an idealised scientific process. The students' lack of explicit knowledge about the term 'scientific method' gave a substantive reason as to why the items in the scientific method NOS subgroup did not load as expected.

However, the two items generated different responses despite being intended to probe the same idea. Most students agreed with item two as it was consistent with both definitions. Students with a procedure definition recognized that different experiments would have different methods, and students with a process view recognised different scientific fields would require different approaches to data collection. For both definitions item two was true, even though they had different interpretations of the term 'scientific method'. This item failed to load as it was a poor discriminator that elicited agreement regardless of the students' beliefs or knowledge.

Item five was intended to probe the same misconception but elicited an informed response from only 20% of the students. During the interviews it became apparent that pseudo naive and neutral responses had been elicited from some students who applied the 'procedure' definition. They had interpreted the item as being about the need to be able to carefully repeat the procedure for verification purposes. Some also recognised the mutually interchangeable nature of some steps, e.g., a 50ml beaker could be used instead of a 100ml beaker. The item failed to load as different interpretations of the item were generated from the same definition of ‘scientific method’.

12.1.4. Empirical item one

Empirical item one, ‘scientific evidence only includes data from the world around us,’ (*M* = 4.12, *SD* = 1.80), failed to load to any construct. This item was problematic in the pilot study and continued to be so throughout the remainder of the study. The underlying belief of the students interviewed was that science was able to study all physically existing phenomena with some students noting that concepts such as ‘God’ were outside the scope of science. The item failed to load as only some students interpreted the item as expected. The written annotations made by students during the quantitative stage of the study support this conclusion with one student writing, ‘our planet?’, and another writing, ‘what do you class as that, everywhere?’ The item was excluded as it generated multiple interpretations that generated pseudo naïve responses. The interviews indicated that the students were fully aware that science studied natural phenomenon, though what terminology best captures this idea is still uncertain as students found both the traditional ‘natural world’ and pilot adjusted ‘world around us’ did not satisfactorily represent this meaning.

12.1.5. Empirical item four

Empirical item four, ‘scientific explanations are created before data is collected’ (*M* = 5.64, *SD* = 1.84), failed to load to any construct. This item was not examined in the interviews due to time constraints, but a probable explanation for its failure emerged from the interview data. The students’ interpretation of what constituted scientific explanations appeared to guide their responses. The data strongly supports the idea that most students held the belief that a proven theory becomes law. Students who read the statement as being about proven explanations (i.e., laws) would have disagreed with the statement as an explanation could only be a law if the data supported it. By comparison, students who read the statement as being about hypothetical explanations (i.e., theory) would have considered the statement accurate and given a naïve response. The students, who were uncertain about what type of explanation was being probed, would have selected the neutral option. Though conjecture, this explanation is consistent with the interview data and sets out a substantive reason as to why the item failed to load.

12.1.6. Summary

Overall the interviews provided complementary data to the quantitative data and the student annotations. The information gained from the interviews helped provide substantive reasons as to why the items failed to load. The exclusion of these items can be justified, but it is notable that they also provided insights into how students interpreted and understood science. The students' responses were predominantly driven by the naïve realist belief that science is able to prove facts.

12.2. Model Constructs

As described in section 10.4.2, the theoretical multidimensional NOS model developed from the literature review had poor goodness of fit. As a result the researcher explored other possible factor solutions (see section 10.5.) by splitting the data into an EFA group (n = 251) to identify other possible constructs, and a CFA group *(n=251*) to analyse goodness-of-fit.

From these analyses a four-factor model provided the most parsimonious factor solution. The researcher labelled the four constructs in the model as;

1) the process of science (α =.78),

2) the purpose of science (α=.51),

3) the certainty of knowledge (α =.80),

4) beliefs of scientists (α =.63).

This section provides interview data to support the four-factor solution suggested by the quantitative analysis. In particular, this analysis highlights how student beliefs about the place of facts in a hierarchical model of the scientific process dominates the way these students understood how science works.

12.2.1. Construct 1: The process of science

Ten items loaded to this construct, with five items having particularly strong loadings. The common theme among the five items was that they collectively described the process of science. In summary, they described how many different methods are used to collect evidence, which is interpreted to form explanations. These explanations describe the world about us but the explanations can change with new discoveries. This construct appeared to capture sound, informed NOS beliefs, but law items seven and eight negatively loaded to this construct, and each elicited strong naive responses from the students. The students' responses to these two items were indicative of two naive realist misconceptions about science: 1) that theories become laws when proven (e.g., "if you're theory was proven unchangeable sort of … sort of unbreakable I guess yeah it could become a law" S024), and 2) that these laws are absolute revelations about how the universe works (e.g., "science which all, everything kind of has to follow … a rule that applies to everything … it's not necessarily certain, but like 99% likely." S085). As with the non-loading items, although the responses suggested that students had informed beliefs, the interviews revealed that they had naive realist beliefs.

When asked to describe 'what is science', the students described it as the acquisition of new knowledge and a means of providing explanations for how the world works. This was consistent with several of the items in the construct and appeared to support the informed beliefs detected by the questionnaire. However what the students went on to describe in the interviews did not support this. Instead, students were responding to the terms 'explain' and 'discover', rather than the other clauses in the statement.

The students' responses to questions about the relationship between laws and theories showed that law items seven and eight were the most accurate measures of how the students perceived the way that science worked. The students consistently described the naive realist view of a hierarchical structure in which proven theories would become laws. Some students did give variations on this response but it seemed to derive from the students contemplating 'soft' scientific disciplines compared to 'hard' scientific disciplines. Participant S093 noted that social science experiments were not what they considered to be science, "like social experiments and things, I'm not really sure if I'd classify that as science as such just because I think science is more on, like I said, a deeper level which isn't really involving people.” (S093).

In the interviews, the students espoused naive realist beliefs about how science worked. They identified that science uses experiments to generate evidence that when done correctly produces obvious and absolute data which reveals the underlying structure of the universe independent of human interpretation. “Theory is the primordial stages of a law … [it] has to go through a series of tests and like experimentation to make it more solid” (S462). This then leads to the facts that are taught in school, “because they're teaching us it, that it must all be the truth” (S202).

Students gave informed questionnaire responses because they identified theories as tentative explanations and they believed that laws could also be tentative due to the previous limitations of an experiment or the technology used. This allowed students to respond to items about the development or modification of scientific explanations in an informed way despite believing that ultimately, a perfect experiment would lead to absolute laws that would not change. These final proven laws would become facts;

> *“…a theory is like, I have this idea, this is kind of how it works. But a theory hasn't been proven. It hasn't got the strong fact behind it. They have to do something like the Newton laws of gravity do.” (S292)*

12.2.2. Construct 2: The purpose of science

Ten items loaded to this construct, with five items having loadings greater than .5. The items in this construct were similar to the first construct in that they contained many of the law and tentative items, but there was not a significant correlation between the two constructs in any of the models tested. The researcher tentatively labelled this construct ‘the purpose of science’ as these items were orientated to what students believed science was trying to achieve (i.e., purpose) rather than how it was trying to achieve it (i.e., process). This construct had a correlation with the third construct (0.41) labelled certainty of knowledge. Both these constructs probed students’ beliefs about scientific explanations.

The items in this construct appeared to capture sound, informed beliefs about the purpose of science amongst students. However, two items in the construct elicited naive responses from the majority of the students; tentative item four and law item five. In addition annotations made on the questionnaires by students indicated that naive realist beliefs were present. For example; beside tentative item seven, which stated scientific books contain absolute truth, one student had selected an informed response but noted beside the statement, “they should’.

During the interviews, the students’ responses to the question ‘what is science?’ repeatedly included the role of facts as being a key distinction between scientific knowledge and those from other fields of inquiry. Areas like literature and social science were seen as imprecise and interpretive, whereas history was noted to be even more factual than science as they believed there could be no arguments over what had happened (e.g., “ history it's already been and so you either know it or you don't” S377). These types of responses reflected naive realist beliefs about the certainty of knowledge and the absoluteness of the conclusions science, and history, could reach.

Further evidence came from the students’ responses to questions about the characteristics of scientists. While students saw imagination as important for developing experiments it was seen by many as detrimental to scientists ability to interpret data and so a characteristic to be avoided, e.g., “scientists have to be very careful when they choose to use it and when they don't” S292 . The students also responded to questions on the relationship between theory and law with hierarchical descriptions of how experiments would prove a theory and establish it as law. These would then become the facts they learnt from their textbooks.

These beliefs about science were inconsistent with the informed questionnaire responses given by the students, which had indicated that they recognised the tentative nature of scientific explanations and the role of human interpretation. From the interviews, it became clear why students had selected options that reflected informed beliefs. The students all noted that no explanation could be exact, but they consistently attributed this to either human error or technological limitations, which would mean explanations were subject to change. Based on this idea, the students held a naive belief about the purpose and certainty of science while at the same time could justify, through reference to error, why scientific explanations were able to change.

12.2.3. Construct three: The certainty of knowledge

This construct contained three items with two of the items having loadings greater than .5. The construct had a .41 correlation with construct two and probed similar ideas with statements that focused on the certainty of knowledge. As with construct two, the interviews revealed that both informed and naive responses were the result of naive realist rationalisations. Students responded to the items based on two guiding principles, 1) what type of explanation the item asking about, i.e., was it law (proven) or theory (unproven) explanation, and 2) that human error and technological limitations are the sources of uncertainty in scientific data. These underlying naive beliefs acted as the guides for the students' response selection and were used to produce either informed or naive responses based on how the students interpreted the items.

If the students interpreted the items as asking about laws, they viewed these explanations as proven facts. Students who considered the explanations to be about theories gave an informed response as they considered these to be still hypothetical explanations. Their description of a theory was naive but allowed them to identify a class of explanations that could change. In this way students gave both informed and naive responses to the item while holding naive realist beliefs about the certainty of science.

Student S468 exemplified how an explanation could be proven but could still change, "as people learn more over time and they have more resources and they realize new things, I guess it could change ... it wouldn't be completely change[d], because the root of it would still be the same." As with the other constructs, naive realist beliefs were used to generate informed responses about NOS tenets. Students' underlying belief was that proven scientific explanations are absolute, but improvements in experimentation can produce more accurate results to support and enhance the existing idea.

12.2.4. Construct 4: Beliefs in science

This construct contained six of the original NOS social tenet items, with five of the items loading above .5. This construct was the only factor that reflected one of the intended tenets. As the items loading to this construct all featured the term *belief* or *value*, it was labelled ‘beliefs in science’. Many students appeared to hold an informed view of this construct which could be simply summarised as beliefs influence scientists. However, annotations on the questionnaires indicated that students had two opinions about scientists’ beliefs; 1) they recognised that scientists would be affected by their beliefs and values, but 2) they viewed this effect as a negative aspect that scientists were expected to abstain from.

In the interviews, the students recognised that scientists would be creative and imaginative in the experimental design and post discovery stages but many believed that as data was self evident, imagination and beliefs would hinder research. As student S355 explained “science isn't about what you believe; it's just about what actually is, it's about fact.” The students indicated that limitations needed to be placed on scientists’ beliefs to stop them from distorting the absolute reality a good experiment could detect.

In this construct, signs did exist of more advanced epistemology. Rather than a naïve realist view of a single reality, the students were advancing into a relativist view such that they recognised that different individuals could perceive different realities, though they tended to advance a laissez faire uncritical relativism that all perceptions are equal (Thoermer & Sodian, 2002). While the students recognised scientists could have different interpretations of the data, they believed that experiments were able to resolve these by revealing an absolute, commonly perceivable universe.

12.3. Summary

The data collected from the questionnaires and interviews provided symmetry in an unexpected way. The researcher had expected the questionnaire to detect beliefs about NOS based on the theoretical model set out at the start of the study. Instead the questionnaire detected alternative constructs that the interview data can be interpreted to support. Rather than an enhanced taxonomy explaining the diversity of NOS responses, this study found that all the students were deriving their explanations from a relatively consistent naïve realist image of science in which theories became fact when proven. The range of responses was the result of the students’ different interpretations of the items. These findings and their implications are discussed further in the discussion.

CHAPTER 13 - DISCUSSION

> *Philosophically, this is an upsetting doctrine. Ever since the time of Newton, scientists and many non-scientists had felt that the methods of science, in principle at least, could make measurements that were precise without limits. One needed to take only enough time and trouble, and one could determine the nth decimal place. To be told that this was not so, but that there was a permanent wall in the way of total knowledge, a wall built by the inherent nature of the universe itself, was distressing.*
>
> *Isaac Asimov*

13.1. Purpose of the Study

The New Zealand science curriculum, and science education researchers worldwide, argues that an informed understanding of NOS is an essential for developing scientific literacy and competency amongst students in a global age. While the details of NOS are subject to debate amongst scholars representing different research fields, a common core of ideals permeates educational literature and national science curricula. These form the basis of the NOS objectives in the *New Zealand Curriculum* (Ministry of Education, 2007), which sets out to develop a scientifically literate and competent populace. While NOS has been part of the New Zealand curriculum for over twenty years its exclusion from explicit national assessments has lead many educators to consider it as ‘pages to just turn over’ (Loveless & Barker, 2000). This study set out to explore the impact of the NOS based curriculum on New Zealand students’ understanding of science by looking at students’ understanding in relation to five key NOS tenets:

1. Scientific knowledge is durable but tentative
2. Scientific laws and theories are not hierarchical
3. Interpretation of scientific data is affected by social and personal beliefs

4. The scientific method refers to the diverse but related group of inquiry skills used to validate scientific knowledge
5. Scientific knowledge is based on empirical evidence

This study focussed on the NOS understanding of year 11 students who have traditionally been the last year to receive compulsory science education. The study used a mixed methods approach in which a NOS questionnaire was used to purposefully select groups of students who were interviewed to explore the range of NOS understanding present in the sample groups.

13.2. Summary of Research Questions

The study set out to address four key questions in relation to students' understanding of the NOS. The first question was to examine the NOS concepts New Zealand secondary students held by their final year of compulsory science education. In this context the researcher set out to explore the way students had integrated their science experiences and prior knowledge to construct their beliefs about how scientific knowledge was generated and validated. The interpretation of data collected to answer this question was based within a constructivist framework that assumed the students' understanding of NOS was a result of how they integrated NOS concepts into the mental construct they held about the way science worked.

The second question set out to compare how the students' understanding of NOS compared to the informed educational NOS tenets espoused by the New Zealand science curriculum and NOS educational researchers. Specifically it set out to compare how students' beliefs about the NOS compared to the five NOS tenets listed above that feature in educational NOS literature.

The third question examined what factors students identified as having influenced their understanding the way that science works. Data concerning this question was gathered only from the interviewed students who were asked to identify sources for beliefs about science. Finally the study set out to identify how the influences and beliefs of students interacted to inform their overall beliefs about NOS.

13.3. Summary of the Research Method

To answer these questions the study following the model of research used by Usher (2009). In this study, questionnaires were used to help purposefully select students to interview. As the established NOS questionnaires trialled for this research were not easily adaptable to the study subjects, the researcher used a modified Likert questionnaire to sample the students (N=502). While the questionnaire was based on established NOS tools, it was intended to measure the five NOS tenets mentioned above. The scores from these would be used to select students for one-to-one interviews (n=22).

Prior to identifying the students to interview, the researcher used CFA to confirm that the questionnaire was measuring the expected constructs. The analysis revealed that the responses were not consistent with the expected NOS sub-theme tenets; instead, some other constructs appeared to link the items for students. The potential constructs were explored by splitting the data and using EFA to identify possible models. CFA was then used with the other half of the data to test the robustness of the factor solutions. From this a four-factor model emerged and the constructs the students used to guide their response choices were identified as 1) the process of science, 2) the purpose of science, 3) certainty of science and 4) beliefs of scientists.

The interviews were scored based on this new model and students were selected to be interviewed based on the average score and the standard deviation. The semi–structured interviews were then conducted with the participants by the researcher. To minimise interviewer bias the researcher was not made aware of which scoring group each participant was in until after the interviews had been completed. The interview had five core questions with the students’ responses then directing what follow up questions the researcher would ask:

- What is science?
- Do beliefs affect scientists?
- What does law and theory mean?
- What does the scientific method mean?
- What has influenced your view of science?

The coding of the interviews was conducted by the researcher. To improve validity of the coding a local NOS expert co-coded one transcript and then independently coded a second to identify aspects of the coding the researcher had overlooked and to provide an alternative way of interpreting and viewing the data. The interview responses and the subsequent coding revealed that while the questionnaire responses had indicated informed beliefs existed in the sample population, the responses had been derived from naïve realist interpretations of the statements.

An analysis was then conducted to identify symmetry between the qualitative and quantitative data. This analysis identified the ways in which the naïve realist beliefs detected in the interview could explain the range of responses seen in the questionnaire data. It also identified how the model of science derived from the student descriptions could be matched to the constructs detected by the four-factor solution.

Statistical experts express concern about the way statistical methods are used in mixed method and educational research (Carifio & Perla, 2007; Henson & Roberts, 2006; Hu & Bentler, 1995; Onwuegbuzie, Bustamante, & Nelson, 2010). In particular they are critical of the practice of researchers only using CFA to confirm a theoretical model and removing items that do not fit that model based solely on Cronbach's alpha or single goodness of fit criteria. In this study the researcher attempted to address such concerns by splitting the data set so that both EFA and CFA analysis could be conducted. This was then followed by attempts to identify substantive reasons to justify both the exclusion of items and the adoption of an alternative factor solution. In adopting this approach the researcher found that the data generated from the qualitative and quantitative phases of the study revealed a common unexpected model of science amongst the students. This model would have been difficult to detect if the researcher had adopted the standard practice of removing items that did not fit the theoretical model.

13.4. Conclusions

Overview

This study set out to explore the way students understood the Nature of Science. The questionnaire was intended to act as a sampling device to select a diverse group of students to interview so that the diversity of student views of science could be captured for comparison to NOS tenets. The analysis of the questionnaire indicated that unexpected constructs were dominating the student views of science, but it also indicated that distinct views of science existed. At first, the interviews appeared to show a diverse range of views about science.

However, as the coding process and close examination of the content peeled away layers, it became apparent that a common model of science existed. This naïve realist model was based on common misconceptions. In the following sections, the student model is first described and then compared to the core NOS tenets. Following that the factors students identified as influencing their beliefs are examined and a final description of how those factors interact to create the students' image of science is outlined.

The students' NOS

While the students selected for the interviews had been identified by the questionnaire as having distinct views and beliefs about science, the interview analysis revealed that a common core belief about the purpose and process of science existed. This view of science identified the proving of facts as the ultimate goal of a hierarchical scientific process in which theories were tested by experiment and when proven would become law and fact. Students in each sample group described variants on this core image of science with different rationales and concepts augmenting the model to make it appear more or less informed with regard to basic NOS tenets. The key components of the students' understanding of science are described in each of the following sections.

During the interviews students made repeated reference to the certainty associated with experimental results. Rather than viewing the data collected as in need of interpretation and analysis, the students from all three groups conceived of it as revealing the true nature of the universe. This view of experimental data is consistent with a realist view of reality in which every person is able to see and recognise the same reality. The students described science as a process that allowed perfect perception, provided the appropriate experiment was done correctly and the technology to measure the phenomena accurately enough existed. In reviewing the students' questionnaire responses and the interview data from each group, it became clear that all the students were holding the belief that a perfect, immaculate perception was possible if an experiment or data collection process was done correctly. Variations in the responses came about as students described ways in which the data could be distorted or unclear. In all the cases, the students ultimately assigned the source of the distortion to human error or technological limitations that in time could be overcome. Students viewed data as definitive but subject to human error or technological constraints. All of the students utilised a core naive realist belief that an objective and comprehendible reality existed outside of the human mind that did not require any interpretation to decipher but could be revealed to anyone if they carried out an appropriate experiment correctly. This view of scientific methodology was consistent with previous findings noted by Baker (1997), Carr et al. (1997) and Osborne et al. (2003).

Where students did see a need for scientific imagination and creativity was in the development of experiments, the conceptualisation of new questions, and the application of new ideas. The students noted in the interviews that scientists would be subject to error if and when, they allowed beliefs to affect how they viewed scientific data. While the students did recognise that such things would affect scientists they again applied a naïve interpretation of what would happen. When probed about scientists with religious beliefs studying evolution, students expected such an individual to steer clear of a field that could be compromising to their religious beliefs and could affect their interpretation of data. Students also described a scientific mindset in which absolute logic and dispassionate interest would dominate the scientific debate. This indicated that students had little exposure to the passions and debates that historically and currently drive science.

The importance of untainted data was crucial to the students' belief that theory and law held a hierarchical relationship. While the questionnaire data had suggested that students were aware of the tentative nature of scientific explanations, the interviews showed that students believed in two distinct classes of explanations. Explanations that were speculative and lacked sufficient proof were associated with the term theory, whereas explanations that were proven or supported by sufficient data where associated with laws. Depending on which type of explanation students believed were being probed by questionnaire items they responded accordingly. Explanations that lacked proof could change and were subject to new interpretations whereas those that were proven would alter very little, except in the case of being refined to a greater degree of accuracy. On the surface, this meant both item responses and some interview responses appeared to be informed, but once examined closely and alongside the students' definitions of theory and law it became apparent that the students held naïve realist beliefs that scientific knowledge was absolute. For the students this was supported by their daily usage of the term theory and by their experience of law and theory in the classroom. The term law did not appear to be affected by the students' daily knowledge of the legal term law which is open to interpretation and change. However, this may be associated with the students' developmental age and they may still be considering things such as legal laws to be absolutely binding.

The students' belief in a hierarchical relationship between law and theory is consistent with their view that experiments provide certainty and proof. Prior to the experiment a scientist develops a theory and then an experiment to test it. Provided the experiment is well designed it can then prove or disprove the theory which either means it becomes a law or a new theory is devised. This view of the process of science is consistent with a naïve realist view but also allows for apparent informed beliefs to be rationalised or integrated into the model. For example students can rationalise ways that explanations may be tentative, i.e., they are theory, or they can integrate the concept of falsifiability without needing to significantly alter this view of science.

Ultimately the students' view of the purpose of science, to prove absolute facts, drives the way in which they conceptualise NOS. Throughout the interviews they referenced facts as the ultimate measure of a scientific explanation. Students rationalised that if it was fact then it must be an absolutely proven explanation with no room left for doubt or interpretation. While the questionnaire had detected informed responses about the certainty of knowledge the interviews had made this clear that those uncertainties were limited to speculative or unproven explanations. Some students also applied this view to laws which they conceded could become more accurate with improved technology, but ultimately an explanation that was deemed a fact was considered to be a true representation of reality.

A single, simple model of science emerged from the diversity of students' descriptions (see Figure 13.1). This model was a linear hierarchical process in which initial investigations and observations would lead scientists to develop possible theories to explain what they saw. These possible explanations were tentative and unproven, and required a degree of controlled imagination and creativity to develop. Once a theory was developed then scientists needed to create a sound experiment that could test the idea. At this point human error and technological limitations could lead to incomplete or inaccurate data being collected. In such instances an explanation would still be tentative and scientists would need to go back and try to create a more definitive or appropriate experiment. If the right experiment is completed, then the data that is generated will be definitive and provide the scientist with the absolute data he needs to either prove or disprove his theory. If proven, the theory would then become a law and provided it continued to be supported by experimental evidence it would ultimately become a fact.

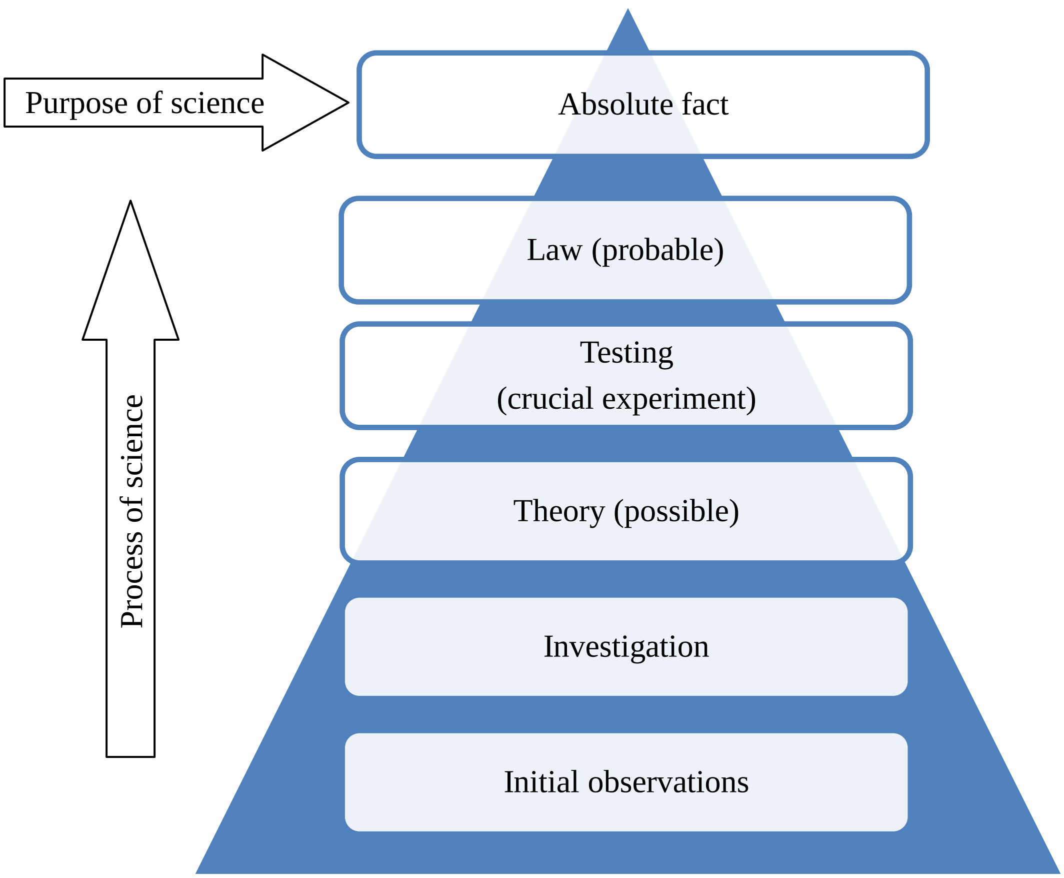

Figure 13.1. Interview derived hierarchical model of science

Note: summed up by the student quote “it’s all proven”

This model also captures the four constructs detected by the EFA analysis of the questionnaire data and supports other research findings that multidimensional constructs are in action (Deng et al., 2010; Sandoval & Morrison, 2003; Tsai, 1999, 2006). However, this research concluded that those constructs are not the same ones used by NOS experts or those taught NOS tenets. The two primary constructs that dictate how students view science are beliefs about the purpose of science, i.e., proving facts, and the process of science, i.e., how to prove the facts. The other two constructs are embedded in this model. The students' views on the certainty of knowledge are reflected in their view of two distinct forms of explanations, i.e., unproven theory and proven law, and their appropriation of scientific uncertainty to human error and technological limitations. Finally, the students viewed scientists' beliefs and imagination as a necessary evil that needed to be controlled. Beliefs could help a scientist pursue and investigate an idea but it needed to be controlled once the data had been generated. In the same vein, imagination and creativity were helpful in design and application stages of the process but needed to be suspended when data was being examined objectively.

Comparison to NOS tenets

The raw quantitative data had indicated that students possessed diverse NOS beliefs as shown by the range of item responses. This led the researcher to initially conclude the New Zealand curriculum had been making a beneficial impact on student epistemologies or at least embedded some of the NOS tenets into students' beliefs about science. The surface appearance was that a range of NOS views were present amongst the students. However, as the data were further analysed it became clear that a common model of science was present. Rather than different beliefs governing the responses, students had been able to rationalise different responses to match their interpretation of the items. The emergent model described above is very different from the NOS tenets that are considered foundational to sound beliefs about science. In this section, the stages of the student derived model are compared and contrasted to informed NOS tenets.

The hierarchical relationship of law and theory play a key role in defining the concepts embedded in the model described above. This known NOS misconception affected not only the students' beliefs about these important scientific terms, but it also allowed other NOS tenets to be rationalised in a way that allowed students to maintain naïve realist beliefs. Theory and law are two important concepts that act as the pinnacles of scientific knowledge. Laws reflect the relationship between phenomena, such as Mendel's law of inheritance, whereas theories explain phenomena, such as Atomic theory. In the student model both law and theory are seen as being explanations, with the distinction being that law is proven whereas a theory is unproven. This finding was similar to the research of Griffiths and Barry (1991), though only two students in this study associated scientific laws with legal laws, and of Meyling (1997) in that students used everyday definitions of law and theory.

With this distinction students were able to assimilate other NOS statements. As theoretical explanations were unproven they could then also be tentative and subject to change. By comparison, laws were proven and so these explanations were not tentative, but instead were certain. This rationalisation allowed students to give questionnaire responses that appeared to be informed beliefs about the tentativeness of scientific explanations; however, they were based on a naïve realist belief and assimilated in such a way that they did not capture the true nature of the NOS concept. The students were able to rationalise a way for uncertainty to fit the model of science they had but in doing so they distorted the informed NOS tenet that all scientific knowledge is robust but tentative.

The transition from theory to law also allowed another aspect of NOS to be assimilated in an inappropriate way. The students believed that the right experiment would reveal clear precise results. The student view of experiments and data were naïve realist interpretations. This fitted the model as it justified why some explanations were tentative and others certain. It did so by ignoring informed NOS tenets about the nature of observations and inference and the need for scientists to apply imagination, creativity and judgement in interpreting what experimental data mean. Students held a naïve realist belief about the scientists' need to interpret data in that they believed it would distort otherwise obvious results. Embedded within the students' beliefs about experiments was their belief that social and cultural influences should not affect science. In this one aspect the students did appear to hold a belief that was close to a more transitional relativism, in that they recognised scientists' beliefs would affect what they did. However, this was almost universally countered by the statement that scientists should not be affected by these personal aspects.

The model of science described by the students was clearly reflective of a naïve realist belief in which absolute conclusions were possible if the right experiment was designed and correctly implemented. The students did not show any signs of having altered their image of science to accommodate informed NOS tenets and instead provided a range of rationalisations to assimilate any NOS ideas into the model of science they believed was correct. While Griffiths and Barry (1991) identified students' views of law and theory as one of a number of misconceptions, the present study placed this misconception at the centre of the students' views of science. A major influence on the model was the students' repeated reference to fact as being the pinnacle of science. This particular misconception, while noted in the above mentioned research, is not something that has been prominent in NOS literature or teaching and will be discussed further in the discussion and implications section.

What informed the student model?

From the coding of the interviews eight influences were identified as being sources for the students' views of science. The most prolific of these was school and classroom teachers whom students noted had modelled for them what science was. The image of science students received from this source was one in which explanations were proved by follow up experiments and in which absolute answers were given both in the textbook and in class. This perception of certainty in science would also be supported by the students' experience of classroom tests, exams and assignments in which specific knowledge was expected to be recalled (Entwistle & Smith, 2002, Roberts & Gott, 2004). Students identified their experience of science in school as their primary influence on understanding science.

In addition, some of the students identified external educational sources such as books, documentaries and movies as also influencing what they believed science to be. Other students noted the way science was perceived by their family and community as being important. Through the interviews it was also clear that the characteristics students felt scientists needed also shaped their perception of the way science needed to work. The students' epistemology, as revealed in the interviews, also seemed to play a role in shaping their beliefs. When the students compared science to other subjects they routinely made reference to certainty in subjects that were seen to have precise answers (Science and History) as opposed to those that were deemed to be more subjective in their criteria (English and Psychology). This indicated they held naïve beliefs not just about science but about all the subjects they were engaged in.

How do the influences interact?

As stated above the core model that students consistently applied to science is one that reflects a naïve realist view of the scientific enterprise. This view seems based on the naïve epistemology that were implied during the interviews when the students described science compared to the other subjects. Students distinguished those subjects they identified with certainty and those subjects they identified as subjective. This view of the certainty of scientific knowledge then appears to be reinforced by what the students experience in the classroom. Laboratory work is used to prove or reinforce concepts and explanations, while the material itself is given as specific facts and practices to adhere to.

While the teachers may have a more NOS aligned intent the students are seeing these features as reinforcing the naïve realist model of science. In addition to what the students experience in class, the aspects that the students do not discuss are equally as influential. In all the interviews, the students questioned what was meant by the scientific method. This implies that many of the students had little to no experience with either the much maligned ‘cooker cuter’ version or the informed NOS tenet. In the absence of a model for scientific practice the students are attempting to develop a model from what they perceive the goal of science to be and how they think it achieves this. This model is further distorted by the students also lacking sound and accurate definitions of the key terms law and theory. In the absence of the scientific definitions, the students applied a combination of the terms from everyday use with attempts to make the words fit what they believe they mean in science. Many of the students had descriptions that bordered on appropriate scientific definitions but were still influenced by the common hierarchy misconception that theories will become laws.

The classroom is the one place that all the students routinely experience science but they appear to have very little contact with authentic science. Students in these interview groups varied in their interest about the epistemology of science. Some had no clear thoughts or interest in how scientific knowledge is validated whereas others had attempted to understand the process of science even before coming into contact with the study. In the absence of clear NOS tenets however the students had applied their experience of science to their basic view that science set out to prove fact. This naïve realist model of science greatly distorts the students' image of NOS. It twists the few tenets the students come into contact with while reinforcing its own misconceptions. This model is not solely derived from classroom science as some of the interview data suggests; it is common to other subjects. However, it is reinforced by what the students' experience. It is particularly troublesome that for most of the students who do not pursue science any further, it will be this model that will dominate their science related future discussions.

The student derived model of NOS was not related to the theoretical construct anticipated by the researcher. Instead their model was driven by a view that facts were the driving purpose behind the scientific process. This vision of science appears to be dominated by educational practices that are reflected by a didactic, realist science environment. The students were integrating any informed NOS tenets they encountered into the naïve realist model without questioning the validity of the model. The students were basing their responses to the questionnaire items on only a simple set of heuristics; 1) science sets out to prove fact, 2) a proven theory becomes a law, 3) that data to prove fact is exact and unambiguous unless human error or technological limitations interfere. From these beliefs the students were able to maintain a naïve realist model that was able to integrate informed ideas such as the tentativeness of explanations and the role of scientists' beliefs, without having to change their core understanding of what science is.

The overall conclusion must be made that the NOS strand of the New Zealand curriculum is not impacting student beliefs as intended. The intuitive model students develop is robust and reinforced by the students' perception of the science experiences they encounter in the classroom. It also appears to be consistent with their base epistemology which does not appear to have developed much beyond naïve realist beliefs. However, an encouraging aspect of the study does exist. During the interviews some of the students noted that their participation in the study had caused them to question some of these beliefs. This indicates that students in year 11 are capable of developing a more informed NOS model, provided they are engaged by teachers in the question of what is science. Even more encouraging was that during the interviews, seven of the students began to question some of the assumptions about laws and theories that they had made at the start of the interview process. For example, S410 said, “Things that have been proven to be true. Or, like false. Um, but then it's like they probably had scientific laws back in the day that were true but have been proven wrong, so. I think it's always good to question the laws.”

13.5. Informing Teaching and Research Practice

Osborne and Freyberg (2001) identify familiarity with students’ prior knowledge as crucial for science teaching. In terms of NOS, knowing how students think of and perceive science is critical for establishing what needs to be achieved and how it can be achieved. The NOS model described by students was a naive realist interpretation of science. While this was a discouraging discovery, given the inclusion of NOS in the New Zealand curriculum, there were three aspects of the findings that indicate practical steps could vastly alter this image of science. First, students were willing to think about what NOS is; second, the naïve realist model they held was built on misconceptions about the purpose and process of science that are known to be alterable; and third, the classroom practice of teachers, as the primary source of students’ views on NOS, can become more realistic by actively identifying opportunities to explicitly link NOS concepts to classroom topics, (e.g., using experimental data to introduce a topic so students derive the model from the data they gather).

During the interviews some of the students had stated that they had been trying to understand the process and purpose of science with the help of teachers and peers, for example “… so just talking to him (teacher) about science things really kind of helped me understand science quite a lot more...” (S021). In addition other students noted that the questionnaire had ‘got them thinking’ about what some of the statements meant or began to reflect during the interviews on some of their beliefs. Both these observations indicate that at least some of the students, if given space to engage in a dialogue about NOS, will engage in a search for deeper justifications of scientific claims. The implication for teaching practice is to create this space and to allow such dialogues to become routine parts of lessons and class experiments. A challenge to this objective is highlighted by the study of

Campanile, Lederman and Kampourakis (2013) which found limited implicit NOS coverage in commonly used textbooks. They also noted that in the context of the development of Mendelian genetics, which they focussed on, textbooks provided simplified historical explanations of this key biological idea glossing over many of the personal, social and historical contexts involved in the shaping and acceptance of this idea. While any textbook or scientific lesson must involve a degree of simplification in order to focus on the most salient points, explicit mention and examples of the historical and social contexts involved in the development of scientific thought is essential in helping all students develop a realistic understanding of how science works. Both textbook writers and teachers should use supplementary material that can help students explicitly examine the role of NOS in the development of scientific ideas within the necessary confines of keeping the overall lesson focussed on key salient points, both about the idea being communicated and the core NOS ideas that are relevant.

The naïve realist model that was derived from the students' description of science is based on their understanding of the terms law and theory. The students consistently described a hierarchical view of the relationship between the two concepts, with experimental evidence playing the role of arbiter between the two;

> *"I feel a theory is the primordial stages of a law. Because you have a hypothesis which is an educated guess … then you can't base things on a hypothesis because a hypothesis has to go through a series of tests and like experimentation to, like make it more solid I'd say. I'd say a theory is a, not as solid as a law, but it's more solid than a hypothesis because it's actually been tested and proven to be, it can work. I'd say a theory can work, whereas a law will work, and a hypothesis might work." (S462)*

This view was reinforced by the students with what they perceived to occur in the classroom and how the two terms are used in everyday language. This primary pillar of the naïve realist misconception is an obvious place in which teachers can correct students' understanding of science. By explicitly defining scientific theory and law, and by using the terminology correctly in class, teachers can help their students to derive a more appropriate model of science.

While this particular recommendation is not new and is seen repeatedly in the literature, it is not identified in the New Zealand NOS objectives. The students' lack of knowledge about what is meant by law and what is meant by theory is seen in this study as a primary feature of the naïve realist model. In addition though, this study identifies an aspect not common to the NOS literature, the students' belief about what is a fact. While science is said to be based on facts, students perceive it to be about proving facts, rather than using them. An additional recommendation of this study then is the need to ensure students also receive explicit instructions about what *fact* means in science. This could also be reinforced by getting students to research the fact about the value of gravity or the value of atomic mass numbers. In both these cases the students will find that while the theory underlining the concept is unchanged, the values and the factual measurements do alter.

The final implication for teaching practice is the need to ensure that teachers examine their classroom practice to ensure the practices they use are not naively interpreted by students. The interviewed students identified their teacher and school as the dominant sources for their beliefs about science. Not only does this mean that teachers should be given ample resources and training to learn about key NOS tenets, but they should also be encouraged to recognise where more authentic teachable opportunities exist. For example the students' associated experiments with proof of a concept covered in class. A more student-centred inquiry based approach could see students do the experiment prior to the theory and then be guided through the interpretation process to reach a tentative but robust conclusion. Strategies such as this would also allow NOS tenets and concepts to become part of the regular classroom discussion rather than being separate units of work.

In addition to teaching practices two research based recommendations come out of the study. The first is the importance of qualitative data in ensuring that quantitative tools are detecting what the researcher hopes to be measuring. This resonates with published work done since the study such as the Deng et al (2011) recommendation for the use of more qualitative based forms of assessment and with Chen, Chang, Lieu, Kao, Huang and Lin's (2013) development of the Students' Ideas about Nature of Science (SINOS) questionnaire which used students descriptions of NOS that were taken from other theses and books.

In the case of this study, the initial quantitative data indicated that informed NOS ideas were present amongst the students. However the qualitative data revealed that all the students held a very similar naïve realist belief about science and that they were able to rationalise response choices that while appearing informed were based on naïve beliefs. The implication for NOS research practice is that the assumptions that validated NOS tools are detecting what they are expected to detect should be checked with at least some interviews to ensure the participants are not rationalising pseudo informed responses.

Tied to this is a second recommendation that the methodology recommendations of statistics experts should be applied to NOS research. During the development of the questionnaire for this study the researcher found no evidence in the recent literature that designers of NOS tools had tested the assumption that NOS constructs were responsible for participants' responses. While NOS experts have the declarative knowledge constructs to guide their interpretation of the items, this is not necessarily true of study participants.

By following the recommendations of Hodis (2011, May) and published recommendations on EFA, CFA (Costello & Osborne, 2005; Henson & Roberts, 2006) and model fit (Hu & Bentler, 1995, 1999) the researcher was able to identify a factor solution that had greater symmetry to the qualitative data of the interviews. While the use of separate CFA and EFA did require larger samples groups, it also ensured that the researcher did not recreate a construct based on published research, but instead on the data collected. While the researcher was not an expert in statistical methods and a number of mistakes and limitations slowed the research process, the eventual product was enhanced by applying these particular methodology practises.

13.6. Limitations of the Study

Unlike many of the natural sciences that can focus on reductionist aspects of phenomena, social science focuses its studies on human derived, emergent phenomena. As such it is not possible to generate data that is not affected by human traits and perceptions, even before the researcher introduces their own beliefs as they try to interpret the data.

Social research must continually re-examine and compare research to help identify causal versus correlation relationships as the phenomena in question is studied in different situations with different participants who introduce their own unique variables. Ultimately the researcher hopes that they will be able to identify applicable (though not necessarily universal) implications.

In this study the research failed to detect any informed NOS concepts in the year 11 students who took part in the study and instead detected a common model of science amongst the participants that reflected a realist understanding of science. While the researcher utilized a mixed methods approach to find symmetry between data sources to increase the validity of the study, methodological limitations need to be recognized as potential influence on the robustness of the conclusions and the accuracy of the data collected.

The study set out to use a questionnaire to purposefully sample students for interviews about NOS beliefs. The initial sample size of 502 students was sufficient to conduct this research, however, the researcher then decided to split the data to conduct EFA and CFA to test the theoretical model. At this stage the sample sizes were reduced to 251. Given the significant impact the EFA and CFA results had on altering the direction and conclusions of this study a larger sample would have been preferred by the author. Any subsequent study should have at least 300 valid participants for each EFA and CFA sub sample.

The initial sample size of 502 was based on four of the schools approached agreeing to take part in the study. More schools could have been approached but the researcher was limited by the number of co-educational schools in the region selected and feasibility (e.g., the practical need to be able to travel to the schools involved on multiple occasions). An additional school could have been involved but the researcher excluded the school as it had taken part in the initial pilot studies.

A known threat to the validity of the questionnaire responses was that female participants did not select outlier responses as often as male students did. This potentially biased the interview groups by more often scoring male students into the higher and lower groups than female students. This could have been avoided by the researcher splitting the male and female data sets in two and treating the data separately. The questionnaire data also disproportionately excluded low ability students. Of the 30 questionnaires that were excluded, the majority were from students in the low ability classes who stopped completing the sheet after the first page. This suggests that a reduced version of the questionnaire needs to be used if valid data is to be collected from this group and if they are to be selected for interviews at a later date. In this case a format that includes only the key discriminator items or that involves non-verbal assessments may be more appropriate.

Ultimately the sample technique involved in this study resulted in skewed results. By purposefully selecting students and then inviting them to take part in the interview stage, the interviewed students were in effect self selected as only those who were interested in science returned the request forms and arrived for the interview. The result was that the majority of the interview participants had positive views about science that they were keen to express or engage in. A few participants declared that they had limited knowledge of science and struggled to articulate responses to some of the interviews questions, but overall the interviewees were noted by the teachers involved to be their more able science students.

This introduced a potentially significant skew in the interview data as students who did not identify as strongly with science or hold strong views about the nature of science, were less inclined to take part in the interviews. The self-selection issue is difficult to overcome without some form of enticement to attract a broader representative sample, though such enticements could themselves act to skew the sample. The hope was that enough students were willing to engage with the researcher that they were willing to take time from their regular class to be interviewed. For students from Maori and Pacifica backgrounds, focus group interviews would have been a better forum to encourage their participation as a number of students who on the questionnaire day indicated they were willingly to take part in the interviews, later changed their mind when they were approached to be interviewed but their peers were not.

While the teachers generally noted that the students taking part in the study were higher achieving students, privacy requirements meant that the researcher had no independent way to confirm or correlate this anecdote. In future studies a valid measure of the students’ scientific achievement would be an important feature to correlate with their NOS beliefs.

The self-reported nature of the data is also a possible source of error. This study measured the students' espoused scientific views and reported on their interpretation of what they had experienced in class. This is not an independently verifiable measure unless the researcher is embedded in the students' classroom experience for a prolonged time. Students may have (unintentional) selective memory about what they have experienced and been taught or they may not correctly recall the way events or experience occur. In this instance the researcher relied solely on self reported data. Longitudinal studies could compare what the students have experienced in class with what they recall and could also measure their enacted practices of dealing with scientific knowledge claims. An improvement on the methodology used in this study would have been to ask for samples of where the teachers believed they included core NOS tenets in their lessons to date.

While the researcher had attempted to reduce language and comprehension issues through the pilot studies an unexpected though insightful source of error emerged. The students lacked familiarity with core scientific terms such as law, theory and scientific method. Students instead derived their interpretations for items including these terms from their beliefs about the way science worked and what they thought the terms referred too. Though this was not anticipated by the researcher, it needed to be taken into account during the interview phase of the study. As noted by Solomon (1986) students' responses to questions such as what a scientists look like are driven as much by what they deem they need to express to the person asking the question, along with what technical language limitations they have at the time. It is possible that the students' constant use of the term fact, in their interviews represented a lack of linguistic differentiation rather than an underlining epistemological belief.

The students' lack of familiarity with these key terms also complicated the items. It became apparent that while the researcher had tried to probe students' beliefs about such things as laws being created by scientists, the additional clauses created confusion and contextual ambiguities. For example, students with similar beliefs about the tentativeness of explanations gave different responses based on whether they thought the item was referring to law or theory. The researcher had attempted to limit multiple clauses in the statements but it is difficult to create easily comprehensible items that are not open to varied interpretations without making the statement overly leading.

As the questionnaire tool was intended to be an aid in purposeful sampling students it was not thoroughly validated. The items were derived from NOS tools that had been used in validation studies but they were combined in a unique way for the theoretical NOS tenet model. There is no evidence that it is able to produce a consistent image, especially as some of the items intended to probe the same constructs failed to correlate as expected. While the items held surface validity with NOS experts, it cannot be considered a robustly tested tool. A follow up validation study, informed by the interviews and excluding the items that failed to load, is needed to establish if other similar sample groups produce the same factor solution.

The hierarchical model developed by the researcher to explain the students item responses also needs further examination. In order to gain access to year 11 students, the researcher had adopted a methodology that required a minimal amount of lost classroom time for the teachers and students. While anecdotal evidence from the researchers current students have indicated that the hierarchical model matches their initial perception of science, the researcher should have gone back to the schools and the students to request more contact time to review the findings. While the model is a derived synthesis of common themes from the interviews, it is intended to be a representation of the students' beliefs and should have been recognizable to them. Not having reviewed this model with participants is a significant limitation of the study. Future research into this model should include time post interview to review the model with new students and to identify where and how their view of science differs. In addition this model may only represent the views of students who have yet to develop mature epistemologies. Additional measures should be made of students' epistemology to see if a correlation exists between their general epistemology and their view of science.

An unintended effect of the study was to promote students to start thinking about NOS tenets. Students noted in the interviews that they had been thinking about some of the items from the questionnaire and their own beliefs about science. It is likely that using a sequential mixed methods study the researcher altered at least some of the students' responses. With more time the study could have asked the interview students to retake the questionnaire so to identify if any of their responses had altered as a response to answering the questionnaire. This limitation indicates that the argumentative resource framework may be a better measure of the students' scientific understanding as it examines how they think about the issues rather than measure the students' declarative knowledge (Deng et al., 2011).

Finally the timeframe allowed for the study, in terms of both available contact time and the period of data collection, both act as limitations to the study's conclusion. As already noted a number of the methodological limitations were subject to the researchers need to limit the amount of interference the study would have on the students' learning. As access to examination year classes in New Zealand is closely controlled by schools to ensure researchers are not taking away valuable teaching time, much of the educational research is focused on non-examination years or on undergraduate courses.

As this study wanted to examine the NOS beliefs of students at the end of compulsory science classes, the researcher adopted a research protocol that would be most likely to be conducive to gaining the data needed while limiting the impact on the students' learning. The limitation of this choice was an inability to re-engage or further probe student ideas and beliefs. This time constraint also meant the researcher only probed students' ideas at the start of the school year. It is probable that through the year the students would have developed and integrated more of the NOS tenets and even altered the way of thinking about science. Future studies should measure the students' views through the year.

13.7. Implications

The prevalence of a hierarchical view of science is a significant impediment to the development of widespread informed understanding of science. The inclusion of NOS in national curricula is an attempt to increase scientific literacy and inclusion to a subject that has often been used as a 'gatekeeper' subject to higher learning opportunities (Claxton, 2008). The students who took part in the interviews all engaged the researcher with attempts to articulate how they perceived science to work. Ultimately their beliefs all reflected naïve realist beliefs but encouragingly they appeared to be derived from a handful of misconceptions.

The aforementioned hierarchical view of science appeared to be the dominant linchpin in the students' model of how science worked. Through the interviews the researcher had to restrain, not always successfully, from guiding students to a realisation that the model they were describing did not match their experience or knowledge of science. From raising the questions about NOS in the questionnaires it seems that only a small directed conversation would be needed to shift the students' understanding of law and theory.

The interviews with students in this study showed that knowledge of NOS tenets as a set of rote definitions is not sufficient for bringing about a change in how they understood science works. While it would result in dogmatic recall of the concepts for tests and quantitative assessments it would not guarantee a more informed populace. Students who were engaged in a NOS unit prior to the study were still trying to appropriately fit the new information into their model of science, which indicates that more guided instruction is needed. The recommendation from this research is that students need time and space to engage in NOS debates, not just at the start of the year, but throughout their science experience. In being allowed to engage in the same debates that scientists have on interpretation of data, in being allowed to explore philosophy of science issues, and by being encouraged to question how robust a given factoid is, students can begin to derive, with guidance, a valid and informed NOS model. Such guided engagement in NOS is similar to recommendations made by Allchin (2011 and 2012) that contextual current and historical vignettes should be used for NOS assessments. However, NOS instruction and assessment need to be pedagogically appropriate and Schwartz, Lederman and Abd-El-Khalick (2012) note that Allchin's contextual scenarios are only useful if students have knowledge of NOS concepts to guide their thinking. In practice both explicit instruction and use of appropriate NOS vignettes are needed to support students developing NOS understanding.

To achieve a pedagogically appropriate mix of guidance and examples requires teachers to be explicitly aware of where in their subjects NOS opportunities exist, and to have the confidence to allow students to pursue them. If students are to be helped to become informed citizens it is important to ensure the teachers have been allowed to develop the tools and expertise to help them achieve this end. This should include not only NOS training for teachers, but greater guidance from curriculum documents about what key terms students need and examples of where in each subject NOS can be integrated with lessons. Added guidance would also lead in turn to textbooks being more explicit about NOS material and of the factors that affect scientific developments (Campanile et al., 2013), a development that this study indicates would help students develop their NOS understanding.

13.8. Suggestions for Future Research

"Sometimes the best answer is a more interesting question." Jack Cohen

As with all research, the results of this study raised more questions than they answered. The study set out to explore the NOS beliefs of New Zealand secondary students using a mixed methods approach. Unlike previous research, this study did not detect multidimensional beliefs, but instead identified a naïve realist perception of science that students applied in a variety of ways to make sense of the science they encountered.

From this work several suggested future research questions arise. Both the four-factor quantitative construct model and the naïve realist qualitative model derived from the interviews require further investigation to explore whether the researcher's derived descriptions of science match students' actual perceptions. In particular, longitudinal and cross sectional studies comparing the naïve realist model with an informed NOS model would be insightful in ascertaining if NOS beliefs significantly morph and evolve and how this is linked to developing epistemology.

A second productive path of inquiry would be to investigate the long term effects of NOS conversations with students. This study would also be beneficial as part of a larger intervention strategy to identify if specific interventions targeting students' beliefs about law, theory and fact alter students' mental model. Associated with this research, looking into the resiliency and adaptability of students' naïve NOS models is needed to identify how best to alter the students' NOS beliefs.

Linked to this research is the need to examine how teachers' NOS lessons are related to students' long term NOS beliefs. Are they integrated into an existing model or are they significant enough to prompt students to change their perception of science? In addition interventions to change students' understanding of law and theory should also be conducted with students who do identify with the naïve realist model to see if altering this hierarchical belief alone is enough to shift beliefs or if multiple aspects of the model need to be addressed.

13.9 Final thought

Educational NOS must walk a fine line between an image of science that is all knowing and a form of science that can seem to be laissez faire. It should exemplify the great power and insights science has given to humanity, but it should also highlight to students both the modern unknowns of science and the inherently interpretative essence of science. Students should be able to appreciate why Newton could be a prototypical physicist, an archaic alchemist and a religious fanatic. Science has never been a clear and precise human process; it does not operate in exact truths nor does it reveal hidden plans of the universe. Instead, it is a continuously messy and evolving understanding of the reality around us. It is a human attempt to understand a very non-human universe. As educators, we should not despair that students hold naïve views about NOS. As they are presented in tandem with all the other material students have to learn, philosophical distinctions about NOS tenets can seem vague and distracting. Yet, while the naïve realist model described in this study seems robust, it is not absolute. Students' comments that participation in the study raised questions for them about the justification of knowledge indicate the potential to shift their existing understanding. We as educators must make the time to allow students to engage with and challenge their innate folk beliefs about science.

REFERENCES

Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: the impact of a philosophy of science course on preservice science teachers views and instructional planning. *International Journal of Science Education, 27*(1), 15 - 42. doi: 10.1080/09500690410001673810

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*(5), 785-810.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*(4), 417-436.

Abd-El-Khalick, F., & Akerson, V. (2009). The influence of metacognitive training on preservice elementary teachers’ conceptions of Nature of Science. *International Journal of Science Education, 31*(16), 2161-2184. doi: 10.1080/09500690802563324

Afonso, A. S., & Gilbert, J. K. (2010). Pseudo-science: A meaningful context for assessing nature of science. *International Journal of Science Education, 32*(3), 329 - 348.

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching, 36*(3).

Aikenhead, G. S., & Ryan, R. (1992). The development of a new instrument: “Views on Science-Technology-Society” (VOSTS). *Science Education, 76*(5), 477-491.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of Nature of Science. *Journal of Research in Science Teaching, 37*(4), 295-317.

Akerson, V. L., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: A yearlong case study of a fourth-grade teacher. *Journal of Research in Science Teaching, 40*(10), 1025-1049

Akerson, V. L., & Abd-El-Khalick, F. S. (2005). "How should I know what scientists do?--I am just a kid": fourth-grade students' conceptions of nature of science. *Journal of Elementary Science Education, 17*(1), 1-11.

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2010). On the nature of teaching nature of science: Preservice early childhood teachers' instruction in preschool and elementary settings. *Journal of Research in Science Teaching, 47*(2), 213-233

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2008). Early childhood teachers' views of nature of science: The influence of intellectual levels, cultural values, and explicit reflective teaching. *Journal of Research in Science Teaching, 45*(6), 748-770.

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. *Journal of Research in Science Teaching, 46*(10), 1090-1113.

Akerson, V. L., & Donnelly, L. A. (2009). Teaching Nature of Science to K-2 Students: What understandings can they attain? *International Journal of Science Education, 32*(1), 97-124.

Akerson, V. L., & Volrich, M. L. (2006). Teaching nature of science explicitly in a first-grade internship setting. *Journal of Research in Science Teaching, 43*(4), 377-394.

Albaum, G., Best, R., & Hawkins, D. (1981). Continuous vs. discrete semantic differential scales. . *Psychological Reports, 49*, 83-86.

Aldridge, J., Taylor, P. C., & Chen, C. C. (1997). *Development, validation and use of the Beliefs About Science and School Science Questionnaire (BASSSQ)*. Paper presented at the National Association for Research on Science Teaching, Chicago, Il.

Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching, 34*(1), 39-55.

Anfara, V. A., & Mertz, N. T. (2006a). Conclusion: Coming full circle. In V. A. Anfara & N. T. Mertz (Eds.), *Theoretical frameworks in qualitative research*. Thousand Oaks, California: Sage Puplications.

Anfara, V. A., & Mertz, N. T. (2006b). Introduction. In V. A. Anfara & N. T. Mertz (Eds.), *Theoretical frameworks in qualitative research*. Thousand Oaks, California: Sage Puplications.

Austin, L. (1997). Teaching and learning about the nature of science. In B. Bell & R. Baker (Eds.), *Developing the science curriculum in Aoteoroa New Zealand*. Auckland: Longman.

Baker, F., & Glynn, L. (1997). Changing science assessment practice through teacher professional development: Some case studies. In B. Bell & R. Baker (Eds.), *Developing the science curriculum in Aotearoa New Zealand*. Auckland: Longman.

Baker, R. (1997). What is science 'about'? In B. Bell & R. Baker (Eds.), *Developing the science curriculum in Aoteoroa New Zealand*. Auckland: Longman.

Barker, M. (2004). Spirals, shame and sainthood -- more ripping yarns from science. *New Zealand Science Teacher*(106), 6-14.

Barker, M. (2006). Ripping yarns: A pedagogy for learning about the nature of science. *New Zealand Science Teacher*(113), 27-36.

Barker, M. (2009). Science teaching and the NZ curriculum. *New Zealand Science Teacher*(120), 29-33.

Bartholomew, H., Osborne, J., & Ratcliffe, M. (2004). Teaching students ideas-about-science: Five dimensions of effective practice. *Science Education, 88*(5), 655-682. .

Baxter Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist, 39*(1), 31-42. doi: 10.1207/s15326985ep3901_4

Bell, B. (2005). Pedagogies developed in the learning in science projects and related theses. *International Journal of Science Education, 27*(2), 159 - 182.

Bell, B., Osborne, R., & Tasker, R. (2001). Finding out what children think. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 151-165). Hong Kong: Heinemann Education.

Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (1998). Implicit versus explicit nature of science instruction: An explicit response to Palmquist and Finley. *Journal of Research in Science Teaching, 35*(9), 1057-1061.

Bergman, M. M. (2010). On concepts and paradigms in mixed methods research. *Journal of Mixed Methods Research, 4*(3).

Borda, E.J., Burgess, D.J., Plog, C.J., DeKalb, N.C., Luce, M.M. (2009) Concept maps as tools for assessing students' epistemologies of science. *Electronic Journal of Science Education, 13(2)*.

Buaraphan, K., & Sung-Ong, S. (2009). Thai pre-service teachers conceptions of the nature of science. Retrieved 13/01/2010, from http://www.ied.edu.hk/apfslt/v10_issue1/buaraphan/

Byrne, B. M., & Watkins, D. (2003). The Issue Of Measurement Invariance Revisited. *Journal of Cross-Cultural Psychology, 34*(2), 155-175. doi: 10.1177/0022022102250225

Cabrera-Nguyen, P. (2010). Author guidelines for reporting scale development and validation results. *Journal of the Society for Social Work and Research, 1*(2), 5. doi: DOI: 10.5243/jsswr.2010.8

Campanile, M., Lederman, N., & Kampourakis, K. (2013). Mendelian Genetics as a Platform for Teaching About Nature of Science and Scientific Inquiry: The Value of Textbooks. *Science & Education*, 1-21. doi: 10.1007/s11191-013-9607-4

Campbell, B. (1998). Realism versus constructivism: Which is a more appropriate theory for addressing the Nature of Science in Science Education? *Electronic Journal of Science Education, 3*(1).

Carifio, J., & Perla, R. J. (2007). Ten common misunderstandings, misconceptions, persistent myths and urban legends about Likert scales and Likert response formats and their antidotes. *Journal of Social Sciences, 3*(3), 106-116.

Carr, M., Barker, M., Bell, B., Biddulph, F., Jones, A., Kirkwood, V., . . . Symington, D. (1997). The constructivist paradigm and some implications for science content and pedagogy. In B. Bell & R. Baker (Eds.), *Developing the science curriculum in Aotearoa New Zealand*. Auckland: Longman.

Chen, S. (2006). Development of an instrument to assess views on nature of science and attitudes toward teaching science. *Science Education, 90*(5), 803-819.

Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? *Journal of Educational Psychology, 94*(2), 327-343.

Claxton, G. (2008). *What's the point of school? Rediscovering the heart of education*. Oxford: Oneworld Publications.

Clough, M. P. (2006). Learners' response to the demands of conceptual change: Considerations for effective nature of science instruction. *Science Education, 15*(5), 463-494.

Clough, M. P., & Olson, J. K. (2008). Teaching and assessing the nature of science: An introduction. *Science & Education, 17*(2/3), 143-145.

Cohen, J., & Stewart, I. (1995). *The collapse of chaos: Discovering simplicity in a complex world*. London: Penguin Books.

Coll, R. K., Dahsah, C., & Faikhamta, C. (2010). The influence of educational context on science learning: A cross national analysis of PISA. *Research in Science & Technological Education, 28*(1), 3-24.

Cosgrove, M., & Osborne, R. (2001). Lesson frameworks for changing children's ideas. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 101-111). Hong Kong: Heinemann Education.

Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. *Science Education, 79*(3), 313-333.

Costello, A. B., & Osborne, J. W. (2005). Best practices in Exploratory Factor Analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research & Evaluation, 10*(7).

Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: SAGE.

Creswell, J. W., & Tashakkori, A. (2007). Editorial: Developing publishable mixed methods manuscripts. *Journal of Mixed Methods Research, 1*(2), 107-111. doi: 10.1177/1558689806298644

Crowther, D. T., Lederman, N. G., & Lederman, J. S. (2005). Understanding the true meaning of nature of science. *Science and Children, 43*(2), 50-52.

Dawkins, R. (2009). *The greatest show on earth: the evidence for evolution*. London: Transworld Publishers.

Deng, F., Chen, D.-T., Tsai, C.-C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education, 95*(6), 961-999. doi: 10.1002/sce.20460

Deniz, H. (2011). Examination of changes in prospective elementary teachers' epistemological beliefs in science and exploration of factors meditating that change. *Journal of Science Education and Technology*, *20*(6), 750-760. doi: 10.1007/s10956-010-9268-x

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: A national study. *Journal of Research in Science Teaching, 45*(10), 1083-1112.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. London: Open University Press.

Eflin, J. T., Glennan, S., & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching, 36*(1), 107-116.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education, 85*(5), 554-567.

Entwistle, N., & Smith, C. (2002). Personal understanding and target understanding: Mapping influences on the outcomes of learning *British Journal of Educational Psychology, 72*(3), 321-342.

Evans, B. C., Coon, D. W., & Ume, E. (2011). Use of theoretical frameworks as a pragmatic guide for mixed methods studies. *Journal of Mixed Methods Research, 5*(4), 276-292. doi: 10.1177/1558689811412972

Fallowfield, L. (1995). Questionnaire design. *Archives of Disease in Childhood, 72*(1), 76-79. doi: 10.1136/adc.72.1.76

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*(2), 335-347.

Feilzer, M. Y. (2010). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research, 4*(1), 6-16.

Fleer, M., & Robbins, J. (2003). "Hit and run research" results in early childhood science education. *Research in Science Education, 33*(4), 405-431.

Ford, M. (2008). 'Grasp of Practice' as a Reasoning Resource for Inquiry and Nature of Science Understanding. *Science & Education, 17*(2), 147-177. doi: 10.1007/s11191-006-9045-7

Freyberg, P., & Osborne, R. (2001). Assumptions about teaching and learning. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 82-90). Hong Kong: Heinemann Education.

Gould, D., Kelly, D., Goldstone, L., & Gammon, J. (2001). Examining the validity of pressure ulcer risk assessment scales: developing and using illustrated patient simulations to collect the data. *Journal of Clinical Nursing, 10*(5), 697-706. doi: 10.1046/j.1365-2702.2001.00525.x

Griffiths, A. K., & Barry, M. (1991). Secondary school students' understanding of the nature of science. *Research in Science Education, 21*(1), 141-150.

Hackling, M. W. (2004). Assessment in science. In G. Venville & V. Dawson (Eds.), *The Art of Teaching Science* (pp. 126-145). Crows Nest, NSW: Allen & Unwin.

Harris, L. R., & Brown, G. T. L. (2010). Mixing interview and questionnaire methods: Practical problems in aligning data. *Practical Assessment, Research & Evaluation, 15*(1).

Havdala, R., & Ashkenazi, G. (2007). Coordination of theory and evidence: Effect of epistemological theories on students' laboratory practice. *Journal of Research in Science Teaching, 44*(8), 1134-1159. doi: 10.1002/tea.20215

Hawking, S. W., & Mlodinow, L. (2010). *The grand design*. New York: Random House.

Henson, R. K., & Roberts, J. K. (2006). Use of exploratory factor analysis in published research. *Educational and Psychological Measurement, 66*(3), 393-416. doi: 10.1177/0013164405282485

Hipkins, R. (2012). *Building a science curriculum with an effective nature of science component*. Wellington, New Zealand: Ministry of Education.

Hipkins, R., Barker, M., & Bolstad, R. (2005). Teaching the "nature of science": Modest adaptations or radical reconceptions? *International Journal of Science Education, 27*(2), 243 - 254.

Hodis, F. (2011, May). [personal communication].

Hofer, B. K. (2000). Dimensionality and Disciplinary Differences in Personal Epistemology. *Contemporary Educational Psychology, 25*(4), 378-405.

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research, 45*(1-2), 85-95.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140. doi: 10.3102/00346543067001088

Hooper, D., Coughlan, J., & Mullen, M. (2008). Structural Equation Modelling: Guidelines for determining model fit. *Electronic Journal of Business Research Methods, 6*(1), 53-60.

Hoyle, R. H., & Panter, A. T. (Eds.). (1995). *Writing about structural equation models*. Thousand Oaks, CA Sage Publications.

Hu, L. T., & Bentler, P. M. (1995). Evaluating model fit *Structural equation modeling: Concepts, issues, and applications.* (pp. 76-99): Thousand Oaks, CA, US: Sage Publications, Inc.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. doi: 10.1080/10705519909540118

Huang, C.-M., Tsai, C.-C., & Chang, C.-Y. (2005). An investigation of Taiwanese early adolescents' views about the nature of science. . *Adolescence, 40*(159), 645-654.

Hume, A. (2008). Nature of scientific inquiry in Year 11 science. *New Zealand Science Teacher*(119), 33-36.

Hume, A., Coco, G., & Green, M. (2007). Shifting sands. *New Zealand Science Teacher*(114), 25-28.

Hume, A., & Coll, R. (2008). Student experiences of carrying out a practical science investigation under direction. *International Journal of Science Education, 30*(9), 1201 - 1228.

Irez, S. (2006). Are we prepared?: An assessment of preservice science teacher educators' beliefs about nature of science. *Science Education, 90*(6), 1113-1143.

Irez, S. (2009). Nature of science as depicted in Turkish biology textbooks. *Science Education, 93*(3), 422-447.

Jackson, D. L., Gillaspy, J. A., Jr., & Purc-Stephenson, R. (2009). Reporting practices in confirmatory factor analysis: An overview and some recommendations. *Psychological Methods, 14*, 6-23.

Jones, A., & Baker, R. (2005). Curriculum, learning and effective pedagogy in science education for New Zealand: introduction to special issue. *International Journal of Science Education, 27*(2), 131 - 143.

Kang, N.-H. (2008). Learning to teach science: Personal epistemologies, teaching goals, and practices of teaching. *Teaching and Teacher Education, 24*(2), 478-498.

Khishfe, R. (2008). The development of seventh graders' views of Nature of Science. *Journal of Research in Science Teaching, 45*(4), 470-496.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of Nature of Science. *Journal of Research in Science Teaching, 39*(7), 551-578.

Khishfe, R., & Lederman, N. G. (2006). Teaching nature of science within a controversial topic: Integrated versus nonintegrated. *Journal of Research in Science Teaching, 43*(4), 395-418.

Kim, S. Y., & Irving, K. E. (2010). History of science as an instructional context: Student learning in genetics and nature of science. *Science and Education, 19*(2), 187-215. doi: 10.1007/s11191-009-9191-9

Kuhn, D., Iordanou, K., Pease, M., & Wirkala, C. (2008). Beyond control of variables: What needs to develop to achieve skilled scientific thinking? *Cognitive Development, 23*(4), 435-451.

Kuhn, D., & Weinstock, M. (Eds.). (2002). *What is epistemological thinking and why does it matter?* Mahwah, NJ: Lawrence Erlbaum.

Laerhoven, H., Zaag-Loonen, H., & Derkx, B. (2004). A comparison of Likert scale and visual analogue scales as response options in children's questionnaires. *Acta Paediatrica, 93*(6), 830-835.

Laws, P. M. (1997). Sc1: scientific investigation: The creation of policy in science education in England and Wales. *Research Papers in Education, 12*(1), 49-67.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359.

Lederman, N. G. (1999). Teachers' understanding of the Nature of Science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36*(8), 916-929.

Lederman, N. G. (2007). Nature of science: Past, present and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education*. New Jersey: Lawrence Erlbaum Associates, Inc.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Lederman, N. G., & Lederman, J. S. (2004a). The nature of science and scientific inquiry. In G. Venville & V. Dawson (Eds.), *The art of teaching science* (pp. 2 - 17). Crows Nest, NSW: Allen & Unwin.

Lederman, N. G., & Lederman, J. S. (2004b). Revising instruction to teach Nature of Science. *The Science Teacher, 71*(9), 36-39.

Lederman, N. G., McComas, W. F., & Matthews, M. R. (1998). Editiorial. *Science & Education, 7*(6), 507-509.

Lederman, N. G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education, 74*(2), 225-239.

Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing the Nature of Science: What is the nature of our assessments? *Science & Education, 7*(6), 595-615.

Lehrer, R., & Scharmann, L. (2006). Scientific thinking and science literacy. In W. Damon & R. M. Lermer (Eds.), *Handbook of child psychology* (6th ed.). New Jersey: John Wiley & Sons.

Limón, M. (2006). The domain generality-specificity of epistemological beliefs: A theoretical problem, a methodological problem or both? *International Journal of Educational Research, 45*(1-2), 7-27.

Liu, S.-Y., & Lederman, N. G. (2002). Taiwanese gifted students' views of Nature of Science. *School Science and Mathematics, 102*(3), 114-123.

Loughran, J. (2010). *What expert teachers do: Enhancing professional knowledge for classroom practice*. Crows Nest, NSW: Allen & Unwin.

Loveless, M., & Barker, M. (2000). 'Those pages we just turn over ...' the "Nature of Science" in science in the New Zealand curriculum. *New Zealand Science Teacher, 93*, 28-31.

Magoon, A. J. (1977). Constructivist approaches in educational research. *Review of Educational Research, 47*(4), 651-693.

Matthews, M. R. (1993). Constructivism and science education: Some epistemological problems *Journal of Science Education and Tecahnology, 2*(1), 359-370.

Matthews, M. R. (1995). *Challenging NZ science education* (1 ed.). Palmerston North, NZ: The Dunmore Press Ltd.

Matthews, M. R. (1998). In defense of modest goals when teaching about the Nature of Science. *Journal of Research in Science Teaching, 35*(2), 161-174.

Matthews, M. R. (2012). Changing the focus: From Nature of Science (NOS) to Features of Science (FOS). In M. S. Khine (Ed.), *Advances in Nature of Science Research* (pp. 3-26): Springer Netherlands.

McClune, B., & Jarman, R. (2010). Critical reading of science-based news reports: Establishing a knowledge, skills and attitudes framework. *International Journal of Science Education, 32*(6), 727 - 752.

McComas, W. F. (2004). Keys to teaching the Nature of Science. *The Science Teacher, 71*(9), 24-27.

McComas, W. F., Almazroa, H., & Matthews, M. R. (1998). The nature of science in science education: An introduction. *Science & Education, 7*(6), 511-532.

McComas, W. F., & Olsen, J. K. (1998). The nature of science in international education standards documents. In W. F. McComas (Ed.), *The nature of science in science* *education: Rationales and strategies* (pp. 41-51). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Meichtry, Y. J. (1993). The impact of science curricula on student views about the nature of science. *Journal of Research in Science Teaching, 30*(5), 429-443.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco: Jossey-Bass.

Meyling, H. (1997). How to change students‘ conceptions of the epistemology of science. *Science & Education, 6*(4), 397-416. doi: 10.1023/a:1017908916810

Ministry of Education. (1997). *Science in the New Zealand Curriculum*. Wellington: Learning Media.

Ministry of Education. (2007). *The New Zealand Curriculum for English-medium teaching and learning in years 1-13*. Wellington: Learning Media.

Ministry of Education. (2011). School decile ratings. from http://www.minedu.govt.nz/Parents/AllAges/EducationInNZ/SchoolsInNewZealand/SchoolDecileRatings.aspx

Monk, M. (2006). How science works: What do we do now? *School Science Review, 88*(322), 119-121.

Morrison, J. A., Raab, F., & Ingram, D. (2009). Factors influencing elementary and secondary teachers' views of the nature of science. *Journal of Research in Science Teaching, 46*(4), 384-403.

Muis, K., Bendixen, L., & Haerle, F. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18*(1), 3-54. doi: 10.1007/s10648-006-9003-6

National Research Council (1996). *National Science Education Standards.* Washington, DC: The National Academies Press

National Research Council (2013). *Next Generation Science Standards: For States, by States*. Washington, DC: The National Academies Press

Nieswandt, M., & Shanahan, M. (2008). 'I just want the credit!' Perceived instrumentality as the main characteristic of boys' motivation in a grade 11 science course. *Research in Science Education, 38*(1), 3-29.

Noel, Y., & Dauvier, B. (2007). A beta item response model for continuous bounded responses. *Applied Psychological Measurement, 31*(1), 47-73. doi: 10.1177/0146621605287691

Onwuegbuzie, A. J., Bustamante, R. M., & Nelson, J. A. (2010). Mixed research as a tool for developing quantitative instruments. *Journal of Mixed Methods Research, 4*(1), 56-78. doi: 10.1177/1558689809355805

Onwuegbuzie, A. J., & Combs, J. P. (2010). Emergent data analysis techniques in mixed methods research: A synthesis. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (2nd ed., pp. 397-430). Thousand Oaks, CA: Sage.

Onwuegbuzie, A. J., & Combs, J. P. (2011). Data analysis in mixed research: A primer. *International Journal of Education, 3*(1).

Osborne, J., & Collins, S. (2001). Pupils' views of the role and value of the science curriculum: a focus-group study. *International Journal of Science Education, 23*(5), 441 - 467.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What ideas-about-science should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*(7), 692-720.

Osborne, R. (2001). Building on children's intuative ideas. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 41-50). Hong Kong: Heinemann Education.

Osborne, R., & Freyberg, P. (2001). Preface. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 1-3). Hong Kong: Heinemann Education.

Peters, E., & Kitsantas, A. (2010). The effect of nature of science metacognitive prompts on science students' content and nature of science knowledge, metacognition, and self-regulatory efficacy. *School Science and Mathematics, 110*(8), 382-396. doi: 10.1111/j.1949-8594.2010.00050.x

Pomeroy, D. (1993). Implications of teachers' beliefs about the nature of science: Comparison of the beliefs of scientists, secondary science teachers, and elementary teachers. *Science Education, 77*(3), 261-278.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception toward a theory of conceptual change. *Science Education 66(2); 211-227 (1982), 66*(2).

Pratchett, T., Stewart, I., & Cohen, J. (2002). *The Science of Diskworld* (2nd ed.). London: Ebury Press.

Pratchett, T., Stewart, I., & Cohen, J. (2003). *The Science of Diskworld II the Globe*. London: Ebury Press.

Pratchett, T., Stewart, I., & Cohen, J. (2005). *The Science of Diskworld III Darwin's Watch*. London: Ebury Press.

Preston, C. C., & Colman, A. M. (2000). Optimal number of response categories in rating scales: Reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica, 104*(1), 1-15.

Quigley, C., Pongsanon, K., & Akerson, V. (2010). If we teach them, they can learn: Young students views of Nature of Science aspects to early elementary students during an informal science education program. *Journal of Science Teacher Education, 21*(7), 887-907. doi: 10.1007/s10972-009-9164-5

Raykov, T., & Marcoulides, G. A. (2011). *Introduction to psychometric theory*. New York: Routledge.

Roberts, R., & Gott, R. (2004). Assessment of Sc1: Alternatives to coursework. *School Science Review, 85*(313), 103-108.

Robottom, I., & Norhaidah, S. (2008). Western science and Islamic learners: When disciplines and culture intersect. *Journal of Research in International Education, 7*(2), 148-163. doi: 10.1177/1475240908091302

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students understanding of the nature of scientific knowledge. *Science Education, 62*(4), 449-458.

Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education, 92*(3), 499-525.

Ryder, J., & Leach, J. (2008). Teaching about the epistemology of science in upper secondary schools: An analysis of teachers' classroom talk. *Science and Education, 17*(2), 289-315.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching, 36*(2), 201-219.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634-656.

Sandoval, W. A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching, 40*(4), 369-392.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345-372.

Scharmann, L. C., Smith, M. U., James, M. C., & Jensen, M. (2005). Explicit reflective nature of science instruction: Evolution, intelligent design, and umbrellaology. *Journal of Science Teacher Education, 16*(1), 27-41. doi: 10.1007/s10972-005-6990-y

Schollum, B., & Osborne, R. (2001). Relating the new to the familiar. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 51-65). Hong Kong: Heinemann Education.

Schraw, G., & Sinatra, G. M. (2004). Epistemological development and its impact on cognition in academic domains. *Contemporary Educational Psychology, 29*(2), 95-102.

Schwartz, R. S., & Lederman, N. G. (2008). What scientists say; Scientists' views of nature of science and relation to science context. *International Journal of Science Education, 30*(6), 727-771.

Schwartz, R. S., & Lederman, N. G. (2008). What scientists say; Scientists' views of nature of science and relation to science context. *International Journal of Science Education, 30*(6), 727-771.

Schwartz, R. S., Lederman, N. G., & Lederman, J. S. (2008). An instrument to assess views of scientific inquiry: The VOSi questionnaire. Retrieved 13/01/2010, from http://homepages.wmich.edu/~rschwart/docs/VOSInarst08.pdf

Seidman, I. (2006). *Interviewing as qualitative research: A guide for researchers in education and the social sciences* (3rd ed.).

Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction, 18*(3), 349-422. doi: 10.1207/s1532690xci1803_3

Smith, L. (1999). What exactly is constructivism in education? *Studies in Science Education, 33*.

Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). How great is the disagreement about the nature of science: A response to Alters. *Journal of Research in Science Teaching, 34*(10), 1101-1103.

Smith, M. U., & Scharmann, L. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education, 83*(4), 493-509.

Smith, M. U., & Scharmann, L. (2008). A multi-year program developing an explicit reflective pedagogy for teaching pre-service teachers the nature of science by ostention *Science and Education, 17*(2), 219-248.

Solomon, J. (1986). Children's explanations. *Oxford review of education, 12*(1), 41-51.

Solomon, J. (2003). Home-school learning of science: The culture of homes, and pupils' difficult border crossing. *Journal of Research in Science Teaching, 40*(2), 219-233.

Solomon, J., & Thomas, J. (1999). Science education for the public understanding of science. *Studies in Science Education, 33*(1), 61-90.

Stewart, I., & Cohen, J. (1997). *Figments of reality: The evolution of the curious mind*. New York: Cambridge University Press.

Streiner, D. L. (2003a). Being inconsistent about consistency: When coefficient alpha does and doesn’t matter. . *Journal of Personality Assessment, 80*, 217-222.

Streiner, D. L. (2003b). Starting at the beginning: An introduction to coefficient alpha and internal consistency. *Journal of Personality Assessment, 80*(1), 99-103. doi: 10.1207/s15327752jpa8001_18

Talbert, B. N. (2007). *Development of the characteristics of science questionnaire (CSQ): assessing student knowledge of the Utah State secondary science core intended* *learning outcome 6 on the nature of science*: Brigham Young University. Dept. of Instructional Psychology and Technology.

Tasker, R., & Osborne, R. (2001). Science teaching and science learning. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 15-27). Hong Kong: Heinemann Education.

Teddlie, C., & Yu, F. (2007). Mixed methods sampling. *Journal of Mixed Methods Research, 1*(1), 77-100. doi: 10.1177/2345678906292430

Telford, M. (2008). Scientific literacy in the Programme for International Student Assessment 2006 (PISA). *New Zealand Science Teacher*(118), 4-8.

Thoermer, C., & Sodian, B. (2002). Science undergraduates' and graduates' epistemologies of science: The notion of interpretive frameworks. *New Ideas in Psychology, 20*.

Trefil, J. (2008). *Why science?* New York: Teachers College Press.

Tsai, C.-C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education, 82*(4), 473-489.

Tsai, C.-C. (1999). The progression toward constructivist epistemological views of science: A case study of the STS instruction of Taiwanese high school female students. *International Journal of Science Education, 21*(11), 1201 - 1222.

Tsai, C.-C. (2006). Biological knowledge is more tentative than physics knowledge: Taiwan high school adolescents' views about the nature of biology and physics. *Adolescence, 41*(164), 691-703.

Tsai, C.-C., & Liu, S.-Y. (2005). Developing a multi-dimensional instrument for assessing students' epistemological views toward science. *International Journal of Science Education, 27*(13), 1621 - 1638.

Usher, E. (2009). Sources of middle school students' self-efficacy in mathematics: A qualitative investigation. *American Educational Research Journal, 46*(1), 275-314.

Vamvakeros, X., Pavlatou, E. A., & Spyrellis, N. (2010). Surevey exploring views of scientists on current trends in chemistry education. *Science & Education, 19*(2), 119-145.

Von Glasersfeld, E. (1987). Constructivism in education. In T. Husen & T. N. Postlethwaite (Eds.), *The International Encyclopedia of Education,* (Vol. Supplement .1, pp. 162–163). New York: Pergamon Press.

Warren, D. (2001). *The nature of science*. London: Royal Society of Cheistry.

Watkins, D., & Cheung, S. (1995). Culture, gender, and response bias: An analysis of responses to the self-description questionnaire. *Journal of Cross-Cultural Psychology, 26*(5), 490-504. doi: 10.1177/0022022195265003

Wong, S. L., & Hodson, D. (2009). From the horse's mouth: What scientists say about scientific investigation and scientific knowledge. *Science Education*, *93*(1), 109-130.

Yardley, L., & Bishop, F. (2008). *Mixing qualitative and quantitative methods: A pragmatic approach* London, UK: SAGE Publications Ltd.

APPENDICES

Appendix A:	NOS Questionnaire for Pilot Study 1
Appendix B:	NOS Questionnaire for Pilot Study 2
Appendix C:	NOS Questionnaire for Phase One Study
Appendix D:	Feedback Sheet for NOS Questionnaire (*Condensed*)
Appendix E:	Questionnaire Student Consent Forms
Appendix F:	Questionnaire Parent Withdrawal of Consent
Appendix G:	Interview Parent Consent Form
Appendix H:	Example of Student Interview (S021)

APPENDIX A

NOS Questionnaire for Pilot Study 1

INSTRUCTIONS The following questionnaire has been created to identify your **personal beliefs** about the way science works. There are **no correct answers** to the following statements **only your personal opinion matters**. **Carefully** read each statement and **circle** the number that **best represents your belief** about it.		**Strongly agree**		**Agree**		**Neither agree nor disagree**		**Disagree**		**Strongly disagree**
1/	The study of science finds out the absolute truth about the natural world.	1	2	3	4	5	6	7	8	9
2/	If a scientific theory is proven right it becomes a scientific law.	1	2	3	4	5	6	7	8	9
3/	Science neutrally assesses the risks and benefits of modern technology.	1	2	3	4	5	6	7	8	9
4/	Professional scientific experiments can never be measured exactly.	1	2	3	4	5	6	7	8	9
5/	In the study of science evidence is found to prove an idea is correct.	1	2	3	4	5	6	7	8	9
6/	Personal beliefs influence scientific observations.	1	2	3	4	5	6	7	8	9
7/	Science can never determine absolute truth.	1	2	3	4	5	6	7	8	9
8/	Past explanations do not affect new scientific explanations.	1	2	3	4	5	6	7	8	9
9/	Scientific laws are fixed and work everywhere.	1	2	3	4	5	6	7	8	9
10/	Scientific explanations do not need evidence.	1	2	3	4	5	6	7	8	9
11/	New evidence changes scientific explanations.	1	2	3	4	5	6	7	8	9
12/	Scientific theories are created to explain patterns in data.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
13/	Scientific laws are created to describe observations made about the natural world.	1	2	3	4	5	6	7	8	9
14/	Scientific experiments produce precise, accurate results.	1	2	3	4	5	6	7	8	9
15/	Scientific data can be interpreted in many different ways.	1	2	3	4	5	6	7	8	9
16/	Scientific evidence only includes data about the natural world.	1	2	3	4	5	6	7	8	9
17/	Values and beliefs influence scientific research.	1	2	3	4	5	6	7	8	9
18/	The scientific method uses many different ways to collect data.	1	2	3	4	5	6	7	8	9
19/	Scientific explanations are absolutely correct.	1	2	3	4	5	6	7	8	9
20/	New evidence can change scientific laws.	1	2	3	4	5	6	7	8	9
21/	Personal values and goals do not influence science.	1	2	3	4	5	6	7	8	9
22/	Scientific experiments always get the same results unless a mistake is made.	1	2	3	4	5	6	7	8	9
23/	No scientific explanation can be proven to be absolutely true.	1	2	3	4	5	6	7	8	9
24/	There is no reason to question established scientific laws.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
25/	Established scientific explanations never change.	1	2	3	4	5	6	7	8	9
26/	The study of science uses many different scientific methods to answer questions.	1	2	3	4	5	6	7	8	9
27/	Scientific explanations are created by interpreting evidence.	1	2	3	4	5	6	7	8	9
28/	When many scientific theories exist, the correct one is identified when enough data is collected.	1	2	3	4	5	6	7	8	9
29/	The scientific method is followed the same way in every culture.	1	2	3	4	5	6	7	8	9
30/	Experience and beliefs affect the interpretation of scientific data.	1	2	3	4	5	6	7	8	9
31/	Scientific evidence is enough to establish if something is true.	1	2	3	4	5	6	7	8	9
32/	Science books contain absolutely true explanations.	1	2	3	4	5	6	7	8	9
33/	Scientific explanations are based upon evidence.	1	2	3	4	5	6	7	8	9
34/	Scientific laws are temporary and change with new discoveries.	1	2	3	4	5	6	7	8	9
35/	Personal beliefs do not influence scientific explanations.	1	2	3	4	5	6	7	8	9

Thank you for taking the time to answer this questionnaire.

APPENDIX B

NOS Questionnaire for Pilot Study 2

INSTRUCTIONS The following questionnaire has been created to identify your **personal beliefs** about the way science works. There are **no correct answers** to the following statements **only your personal opinion matters**. **Carefully** read each statement and **circle** the number that **best represents your belief** about it.		**Strongly agree**		**Agree**		**Neither agree nor disagree**		**Disagree**		**Strongly disagree**
1/	The study of science finds out the absolute truth about the world around us.	1	2	3	4	5	6	7	8	9
2/	If a scientific theory is proven right it becomes a scientific law.	1	2	3	4	5	6	7	8	9
3/	Scientific research is not affected by personal beliefs.	1	2	3	4	5	6	7	8	9
4/	Professional scientific experiments can never be measured exactly.	1	2	3	4	5	6	7	8	9
5/	Scientific explanations are created before data is collected.	1	2	3	4	5	6	7	8	9
6/	Personal beliefs influence scientific observations.	1	2	3	4	5	6	7	8	9
7/	Science can never determine absolute truth.	1	2	3	4	5	6	7	8	9
8/	Past explanations do not affect new scientific explanations.	1	2	3	4	5	6	7	8	9
9/	Scientific laws are fixed and work everywhere.	1	2	3	4	5	6	7	8	9
10/	Scientific explanations do not need evidence to be accepted.	1	2	3	4	5	6	7	8	9
11/	New evidence can change scientific explanations.	1	2	3	4	5	6	7	8	9
12/	Scientific theories are created to explain patterns in the world around us.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
13/	Scientific laws are created to describe observations made about the world around us.	1	2	3	4	5	6	7	8	9
14/	Professional scientific experiments produce exact results.	1	2	3	4	5	6	7	8	9
15/	Scientific data can be interpreted in many different ways.	1	2	3	4	5	6	7	8	9
16/	Scientific evidence only includes data from the world around us.	1	2	3	4	5	6	7	8	9
17/	Values and beliefs influence scientific research.	1	2	3	4	5	6	7	8	9
18/	There is no single scientific method.	1	2	3	4	5	6	7	8	9
19/	Established scientific explanations are absolutely correct.	1	2	3	4	5	6	7	8	9
20/	New evidence can change scientific laws.	1	2	3	4	5	6	7	8	9
21/	Personal values and goals do not influence the way scientific evidence is interpreted.	1	2	3	4	5	6	7	8	9
22/	The scientific method refers to the steps all scientific experiments follow.	1	2	3	4	5	6	7	8	9
23/	No scientific explanation can be proven to be absolutely true.	1	2	3	4	5	6	7	8	9
24/	Scientific laws exist in nature before we discover them.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
25/	Established scientific explanations never change.	1	2	3	4	5	6	7	8	9
26/	Many different scientific methods are used to solve scientific questions.	1	2	3	4	5	6	7	8	9
27/	Scientific explanations are created by interpreting evidence.	1	2	3	4	5	6	7	8	9
28/	Scientific theories become scientific laws when enough evidence is collected.	1	2	3	4	5	6	7	8	9
29/	There is one scientific method that is always used in the same way.	1	2	3	4	5	6	7	8	9
30/	Experience and beliefs affect the interpretation of scientific data.	1	2	3	4	5	6	7	8	9
31/	Scientific evidence does not need to be interpreted.	1	2	3	4	5	6	7	8	9
32/	Science books contain absolutely true explanations.	1	2	3	4	5	6	7	8	9
33/	Scientific explanations are based upon evidence.	1	2	3	4	5	6	7	8	9
34/	Scientific laws are temporary and change with new discoveries.	1	2	3	4	5	6	7	8	9
35/	Personal beliefs do not influence scientific explanations.	1	2	3	4	5	6	7	8	9

Thank you for taking the time to answer this questionnaire.

APPENDIX C

NOS Questionnaire for Phase One Study

Name: ______________________________________ Age: _______ Code: _______________

INSTRUCTIONS The following questionnaire has been created to identify your **personal beliefs** about the way science works. There are **no correct answers** to the following statements **only your personal opinion matters**. **Carefully** read each statement and **circle** the number that **best represents your belief** about it.		**Strongly agree**		**Agree**		**Neither agree nor disagree**		**Disagree**		**Strongly disagree**
1/	The study of science finds out the absolute truth about the world around us.	1	2	3	4	5	6	7	8	9
2/	If a scientific theory is proven right it becomes a scientific law.	1	2	3	4	5	6	7	8	9
3/	Scientific research is not affected by personal beliefs.	1	2	3	4	5	6	7	8	9
4/	Professional scientific experiments can never be measured exactly.	1	2	3	4	5	6	7	8	9
5/	Scientific explanations are created before data is collected.	1	2	3	4	5	6	7	8	9
6/	Personal beliefs influence scientific observations.	1	2	3	4	5	6	7	8	9
7/	Science can never determine absolute truth.	1	2	3	4	5	6	7	8	9
8/	Past explanations do not affect new scientific explanations.	1	2	3	4	5	6	7	8	9
9/	Scientific laws are fixed and work everywhere.	1	2	3	4	5	6	7	8	9
10/	Scientific explanations do not need evidence to be accepted.	1	2	3	4	5	6	7	8	9
11/	New evidence can change scientific explanations.	1	2	3	4	5	6	7	8	9
12/	Scientific theories are created to explain patterns in the world around us.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
13/	Scientific laws are created to describe observations made about the world around us.	1	2	3	4	5	6	7	8	9
14/	Professional scientific experiments produce exact results.	1	2	3	4	5	6	7	8	9
15/	Scientific data can be interpreted in many different ways.	1	2	3	4	5	6	7	8	9
16/	Scientific evidence only includes data from the world around us.	1	2	3	4	5	6	7	8	9
17/	Values and beliefs influence scientific research.	1	2	3	4	5	6	7	8	9
18/	There is no single scientific method.	1	2	3	4	5	6	7	8	9
19/	Established scientific explanations are absolutely correct.	1	2	3	4	5	6	7	8	9
20/	New evidence can change scientific laws.	1	2	3	4	5	6	7	8	9
21/	Personal values and goals do not influence the way scientific evidence is interpreted.	1	2	3	4	5	6	7	8	9
22/	The scientific method refers to the steps all scientific experiments follow.	1	2	3	4	5	6	7	8	9
23/	No scientific explanation can be proven to be absolutely true.	1	2	3	4	5	6	7	8	9
24/	Scientific laws exist in nature before we discover them.	1	2	3	4	5	6	7	8	9

		Strongly agree		Agree		Neither agree nor disagree		Disagree		Strongly disagree
25/	Established scientific explanations never change.	1	2	3	4	5	6	7	8	9
26/	Many different scientific methods are used to solve scientific questions.	1	2	3	4	5	6	7	8	9
27/	Scientific explanations are created by interpreting evidence.	1	2	3	4	5	6	7	8	9
28/	Scientific theories become scientific laws when enough evidence is collected.	1	2	3	4	5	6	7	8	9
29/	There is one scientific method that is always used in the same way.	1	2	3	4	5	6	7	8	9
30/	Experience and beliefs affect the interpretation of scientific data.	1	2	3	4	5	6	7	8	9
31/	Scientific evidence does not need to be interpreted.	1	2	3	4	5	6	7	8	9
32/	Science books contain absolutely true explanations.	1	2	3	4	5	6	7	8	9
33/	Scientific explanations are based upon evidence.	1	2	3	4	5	6	7	8	9
34/	Scientific laws are temporary and change with new discoveries.	1	2	3	4	5	6	7	8	9
35/	Personal beliefs do not influence scientific explanations.	1	2	3	4	5	6	7	8	9

Do you intend to continue to take science classes? Yes Unsure No

Do you think the science you are learning will be useful to you later in life? Yes Unsure No

Thank you for taking the time to answer this questionnaire.

APPENDIX D

Feedback Sheet for NOS Questionnaire (*Condensed*)
Note: The same format used for focus group

Italicised statements are based on informed NOS positions.
Normal font statements reflect a non-informed (naïve) NOS positions.

Theme 1 statements: *Science knowledge is durable but tentative*

7	*Science can never determine absolute truth.*
11	*New evidence can change scientific explanations.*
23	*No scientific explanation can be proven to be absolutely true.*
1	The study of science finds out the absolute truth about the world around us.
19	Scientific explanations are absolutely correct.
25	Established scientific explanations never change.
32	Science books contain absolutely true explanations.

Comments on statements used.

Theme 2 statements: *Laws and theories represent distinct types of knowledge*

12	*Scientific theories are created to explain patterns in the world around us.*
13	*Scientific laws are created to describe observations made about the world around us.*
20	*New evidence can change scientific laws.*
34	*Scientific laws are temporary and change with new discoveries.*
2	If a scientific theory is proven right it becomes a scientific law.
9	Scientific laws are fixed and work everywhere.
24	Scientific laws exist in nature before we discover them.
28	Scientific theories become scientific laws when enough evidence is collected.

Comments on statements used.

Theme 3 statements; *Science is theory laden and socially/culturally influenced*

6	*Personal beliefs influence scientific observations.*
15	*Scientific data can be interpreted in many different ways.*
17	*Values and beliefs influence scientific research.*
30	*Experience and beliefs affect the interpretation of scientific data.*
3	Scientific research is not affected by personal beliefs.
8	Past explanations do not affect new scientific explanations.
21	Personal values and goals do not influence the way scientific evidence is interpreted.
35	Personal beliefs do not influence scientific explanations.

Comments on statements used.

Theme 4 statements; *No single scientific method exists*

4	*Professional scientific experiments can never be measured exactly.*
18	*There is no single scientific method.*
26	*Many different scientific methods are used to solve scientific questions.*
14	Professional scientific experiments produce exact results.
22	The scientific method refers to the steps all scientific experiments follow.
29	There is one scientific method that is always used in the same way.

Comments on statements used.

Theme 5 statements; *Science is based upon empirical evidence*

16	*Scientific evidence only includes data from the world around us.*
27	*Scientific explanations are created by interpreting evidence.*
33	*Scientific explanations are based upon evidence.*
5	Scientific explanations are created before data is collected.
10	Scientific explanations do not need evidence to be accepted.
31	Scientific evidence does not need to be interpreted.

Comments on statements used.

APPENDIX E

Questionnaire Student Consent Forms

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FACULTY OF EDUCATION

Project Title: Exploring year 11 students understanding of Nature of Science concepts

This project has been approved by Victoria University of Wellington Faculty of Education Ethics Committee application no. 17855

The purpose of this study is to explore year 11 students beliefs about Nature of Science (NOS) – what science is and how scientists work. It is hoped that this information will help improve the way science is taught. This research is being conducted as part of my PhD with Victoria University of Wellington.

Participation: If you agree to take part in this study, you will be given a questionnaire on NOS that will take about 20 minutes to do. You may also be asked to take part in an interview to discuss your beliefs about science. This interview will take about 60 minutes and you will be given time to review and if needed correct or change the notes made from your interview.

Confidentiality: Neither you nor your school will be identified in any way. The results of this research will be presented in written and oral form as part of the PhD thesis, but will not use your name. No personal information that would enable anyone to identify you will be used in any work that is created from this research.

Please note that participation in this study is voluntary. You are under no obligation to take part in or to complete this study. Your decision about taking part in this study will not affect your present or future relationship with Victoria University of Wellington. Taking part or not taking part will not affect your grades in any way. If you give agree to take part in this study you have the right to withdraw at any time during the data collection process.

Ethics: If at any time you have any questions or concerns about your treatment during this study contact Dr Judith Loveridge who is the Chair of the Faculty of Education Ethics Committee (telephone: +64 4 463 6028).

Data Storage and Deletion: All digital files will be securely stored on a password-protected computer, and hard copies will be kept in secure storage for five years after the conclusion of the research before being deleted or destroyed. The data will not be identifiable in any way.

Reporting/Dissemination: The results of this study will be submitted as part of a PhD thesis. Aspects of this study may also be submitted for publication in research journals or presented at educational conferences. If you are interested in receiving a copy of the reports generated from this study you can do so by contacting Blair Northcott.

If you have any questions about the study now or at any time in the future, please feel free to contact me using the following contact information: Blair Northcott, School of Educational Psychology and Pedagogy, Faculty of Education, Victoria University of Wellington, PO Box 17-310, Karori, Wellington, NZ, +64 4 463 5233 ext. 8127, blair.northcott@vuw.ac.nz or my supervisor Dr Matt McCrudden, Senior Lecturer, School of Educational Psychology and Pedagogy, Faculty of Education, Victoria University of Wellington, PO Box 17-310, Karori, Wellington, NZ, +64 4 463 5179, matt.mccrudden@vuw.ac.nz.

Sincerely,

Blair Northcott

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FACULTY OF EDUCATION

Participant consent form (student)

Project Title: Exploring year 11 students understanding of Nature of Science concepts

Ethics Application #: 17855

(Please tick the circles to indicate your understanding and/or agreement with each of the following statements).

- o I have had the project explained to me and I have had a chance to ask questions.
- o I understand that taking part in this project will not affect my grades in any way.
- o I understand that I do not have to take part in the research and that I may withdraw from this project without having to give a reason up until the final point of data collection (April 2011).
- o I understand that any information I provide will be kept confidential and that I will not be identified in the research or in any reports on the project or to any party.
- o I understand that any information from this project will be destroyed after five years.
- o I understand that if I am interviewed the researcher will summarize the key points at the end of my interview and that I will be able to make changes to the wording of my responses if I wish.
- o I understand that if I am interviewed I will be given a chance to review a transcript of my interview and I will be able to make changes to the wording of my responses if I wish.
- o I understand that the research findings will be published and shared with teachers and other interested people.

- o I agree to take part in questionnaire stage of the research and to allow my answers to be collected and analysed.

- o I agree to take part in the interview stage of the research if required and to allow my answers to be collected and analysed.

Name:________________________ Date: ____________

Signature:______________________

APPENDIX F

Questionnaire Parent Withdrawal of Consent

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FACULTY OF EDUCATION

Project Title: Exploring year 11 students understanding of Nature of Science concepts

This project has been approved by Victoria University of Wellington Faculty of Education Ethics Committee application no. 17855

The purpose of this study is to explore year 11 students beliefs about Nature of Science (NOS) – what science is and how scientists work. It is hoped that this information will help improve the way science is taught. This research is being conducted as part of my PhD with Victoria University of Wellington.

Participation: Your child has been asked to participate in this study which will involve them responding to a brief NOS questionnaire that will take approximately 20 minutes to complete. This questionnaire asks students to circle responses that most closely correspond to their current beliefs about the way science and scientists work. Following analysis of these questionnaires your child may be asked to participate in interviews to further understand their NOS beliefs. If your child is asked to participate in these interviews a separate consent form will be sent to you before any interviews take place.

Confidentiality: Neither your child nor the school will be identified in any way in the reporting of this research. The results of this research will be presented in written and oral form as part of the PhD thesis, but it will not use your child's name. No personal information that would enable anyone to identify your child or the school will be used in any report generated from this research.
Please note that your child is under no obligation to take part in this study. If you decide you do NOT want your child to participate in this study please complete the consent withdrawal form attached to this information sheet and return it to your child's school. If you agree to your child participating in this study you do not need to send back any forms. Non-participation will not affect you or your child's present or future relationship with Victoria University of Wellington or your child's grades in any way. If you later decide you do not wish your child to participate in this study you have the right to withdraw them from the study at any time during the data collection process which ends in April 2011.
Ethics: If at any time you have any questions or concerns about the treatment of your child during this study, contact Dr Judith Loveridge who is the Chair of the Faculty of Education Ethics Committee (telephone: +64 4 463 6028).
Data Storage and Deletion: All digital files will be securely stored on a password-protected computer, and hard copies will be kept in secure storage for five years after the conclusion of the research before being deleted or destroyed.
Reporting/Dissemination: The results of this study will be submitted as part of a PhD thesis. Aspects of this study may also be submitted for publication in research journals or presented at educational conferences. If you are interested in receiving a copy of the reports generated from this study you can do so by contacting Blair Northcott.

If you have any questions about the study now or at any time in the future, please feel free to contact me using the following contact information: Blair Northcott, School of Educational Psychology and Pedagogy, Faculty of Education, Victoria University of Wellington, PO Box 17-310, Karori, Wellington, NZ, +64 4 463 5233 ext. 8127, blair.northcott@vuw.ac.nz or my supervisor Dr Matt McCrudden, Senior Lecturer, School of Educational Psychology and Pedagogy, Faculty of Education, Victoria University of Wellington, PO Box 17-310, Karori, Wellington, NZ, +64 4 463 5179, matt.mccrudden@vuw.ac.nz.

Sincerely,
Blair Northcott

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FACULTY OF EDUCATION

Participant consent withdrawal form (parent)

Project Title: Exploring year 11 students understanding of Nature of Science concepts

Ethics Application no. 17855

- o I do not wish my child to participate in this research. (Please tick circle to indicate you wish to withdraw your child from this study)

(Please tick the circles to indicate your understanding of each of the following statements)

- o I understand my child will not participate in any stage of this study.
- o I understand that this will not affect my child's grade in any way.
- o I understand that this will not affect mine or my child's current or future relationship with Victoria University of Wellington.

Name of student:__________________________

Name of caregiver:________________________ Date: ____________

Signature of caregiver:______________________

APPENDIX G

Interview Parent Consent Form

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FACULTY OF EDUCATION

Participant interview consent form (parent)

Project Title: Exploring year 11 students understanding of Nature of Science concepts

Ethics Application no. 17855

(Please tick the circles to indicate your understanding and/or agreement with each of the following statements).

- o I understand that participation in this project will not affect my child's grade in any way.
- o I understand that my child does not have to take part in the research and that he/she may withdraw from this project up until the final point of data collection (May 2011).
- o I understand that any information my child provides will be kept confidential and that he or she will not be identified in the research or in any reports on the project or to any party.
- o I understand that any information from this project will be destroyed after five years.
- o I understand that the names of students and school will remain confidential
- o I understand that the research findings will be published and shared with teachers and other interested people.
- o I agree to allow my child to take part in this research project and to allow my child's answers to be collected and analyzed.

Name of student:___________________________

Name of caregiver:_________________________ Date: _____________

Signature of caregiver:______________________

APPENDIX H

Example of Student Interview (S021)

<u>B - Interviewer</u>
It's started on the interview proper. Obviously it's about science. So one of the first things I kind of want to get an idea about is how you would describe science to someone.

<u>S - Student</u>
Science is the learning of how things work and how things around you kind of work, like the atom, molecules, heat conductivity, stuff like that. You know, that science, it's just learning about anything really, and how it works.

B
Yeah. So it's a big picture,

S
Yeah.

B
You're looking at everything that you're interacting with.

S
Yeah.

B
Internal as well as external sort of stuff.

S
Yeah.

B
So when you go along to the doctor you can say, "Oh, my heart's palpitating," instead of saying, "I'm getting a thumping feeling in my chest." So you kind of know.

S
Yeah. What's going on.

B
Yep, that's cool. So given that description, that you're learning about everything around you and inside as well, um, what do you think school science does in terms of that?

S
School science kind of teaches you how to look for it rather than just giving it to you on a plate, I found that they'll give you the experiment for you to do yourself and you learn what's happening and stuff, rather than... If you read a book, it tells you what happens. But with the science at school you learn from doing it and that kind of helps make it, make it learn easier I guess.

B
Yeah, yeah.

S
So it's kind of, yeah. It's kind of just teaching you how to learn, how to learn science.

B
Yeah. Is that different from other subjects?

S
It's definitely quite a lot different. Like I just came from food tech and there you get given a recipe and you make it and, but you know what it's going to be. More of the science you get given a recipe, but you don't know the outcome and you learn a lot more from not knowing than knowing what it's going to be.

B
So you kind of have to go through that discovery process.

S
Yeah, yeah.

B
I'm figuring out what this, what this is.

S
For that react-, for that you create that. Oh, wow, I didn't know that.

B
Yeah. So when it, if someone takes that on outside of school, um, is that something that carries on outside of school for everyone? Or is it just specific for people who are going to go into sciences?

S
I think for whatever purposes you're doing, there's always an element of science that can be applied to it.

B
Yeah.

S
So even if you don't become a scientist or have something to do with science, you still have the knowledge of science of how things work. Like even in like, you know, food, you use science, metalworks, science, computing you use science, lots of things you use science for. So it's quite a universal subject that can be applied to lots of different things, not just like the scientist image, working in a lab or whatever.

B
Yeah, yep. So it's got lots and lots of applications you can use it across the board.

S
Yeah. Yeah, you can even use it in like social, you might be a smart guy, who knows everything.

B
(laughs) Not necessarily a good social thing at times. Um, so we've kind of gone that science is looking at everything. Do you think there's a particular thing that science is trying to do?

S
I think particularly science is trying to, I think get us to, well definitely with the school science it's definitely trying to get us to discover and learn for ourselves. It's definitely trying to do that and if I was to, like, kind of focus on one thing, I guess, I don't know. Cause it does, there are lots of different applications and such.

B
Yeah. So it's got multiple things that...

S
Yeah. It couldn't be narrowed down to just one.

B

There's a number of broad things that it's all doing at once.

S
Yeah.

B
Is that the same for science as a, should we say human endeavor? Or does that have a particular thing that it's trying to do?

S
I guess it's just trying to learn, trying to know, trying to know more about what's around us and how everything works. I guess if there's one thing that science is trying to achieve, it's knowledge.

B
Yeah. So it's just trying to build up our knowledge and increase what we know about the world.

S
Yeah.

B
How do you think scientists go about establishing whether they've found something?

S
If they think they're on to something, I guess they'd just do lots of tests and different sort of things to work out. And once the trial and error has gone through lots, they can, and it comes up with the, well, sort of same results, they can say that they've found something. But if they just, if it's just a one-off, they can't really say that they found it.

B
Yeah.

S
So say it's a theory, they can't say they've found it.

B
Cool. Ok, so core thing for knowing whether you've discovered something is you can keep repeating it.

S
Yeah.

B
Keep getting the same results. You mentioned that, until then it's just a theory. So theory is just an idea about what you think's going on?

S
Yeah.

B
What happens once you've got the results that keep proving it? What would you term that? How would you call that knowledge then?

S
A fact, I guess. Like it's a fact that there's 3 solid states. That's a fact. There's, a, solid, liquid, and gas. There's not going, like, unless, before that it could have been a theory that there could've been 4 states, but until they found it out that there's only 3, then that became a fact.

B
Right. Ok. So using that idea, because it's certainly something we do in science classes here, we talk about solids, liquids, and gasses. Um, what would happen if someone came along and said, "Ah, there's an in-between state"?

S
It would become a theory again until it is proven and tried and tested again. Because that's happening a lot. They're finding getting old research that was found and just double-checking all over and making sure it works.

B
Yeah. What do you think they do that for?

S
Just because lots of things are always changing, always creating new things, you know. They want to make, have the most kind of up-to-date knowledge of the world.

B
Yeah. So in terms of retesting it, do they retest it with the same equipment or would they use the more modern...

S
Well there's new technology that's been developed for us to use.

B
Ok, so every time we kind of make a technological step, we can go back and go, "Ah, now we can do this experiment in even more detail, we can get it more refined."

S
Yeah, yeah.

B
Cool, ok. Um, so shifting from science as a whole and kind of following down this what scientists do line, um, when people are carrying out science, is that, something particular about it that makes it different from say, another topic? Say from a historian or from a geographer or a mathematician?

S
With those sort of things, I mean, mathemeticia's quite kind of universal, but if you just did history, you can't really become like, say, a food technologist, or a chef as easy as it is from science.

B
Right.

S
Because science you can just quickly apply it to the food technology or whatever, but with, you can't, you can't really apply history knowledge to something else that's not history.

B
Right, ok. So one of the, cause you mentioned mathematics being quite universal, so the universaility of science is that I can use it in multiple... That's what makes it kind of a distinct thing.

S
Yeah, yeah.

B

Ok, yep. I think I follow that one. Um, if we keep going, cause we're just kind of refining down and down more, scientists themselves when they're carrying out experiments or carrying out research. Um, they design an experiment, get results, and then they try and create an explanation, or they develop an explanation. Do you see them using their imagination at points in that, or...

S
Yeah, lots of people like, as they're going they go, "I wonder if..." which is quite a big statement around science is, I wonder if. That's how lots of things came from people wondering and imagining what would happen if, say these 2 elements were put together. And add like a certain amount of this. That can create new things.

B
Yeah.

S
Like, yeah, just, and, you know, they might have a dream about something and then they do it, they try it, it works. Imagining has quite a lot to do with science. Even though, it's quite a mix because science is very factual once you get into it, but the facts come kind of from the imagination and going, once again, I wonder if.

B
Yeah. So you can find, using your element example, you can find out the facts about these 2 elements, and then once you know those, you can start to go, well, in that case, I wonder if...

S
Yeah.

B
...when I combine them this is going to happen.

S
Yeah. What sort of reaction will take place.

B
So we really use imagination at the starting point.

S
Yeah. It kind of like... can I draw on this?

B
Yeah, yeah.

S
If there was, this is your like, theory, and this is the end of the experiment kind of.

B
Yeah.

S
We'll you've got it, it kind of goes, *drawing* like.... two triangles. And this is...

B
Oh, kind of like an hourglass.

S
Yeah, yeah, yeah. And this would be imagination, I suck at spelling.

B
Oh, that's ok.

S
And this is fact. And as it goes through, the imagination gets smaller, and the fact gets larger.

B
Right, ok. Ok, so it is like 2 distinct triangles because as one closes, the other one groups up.

S
Yeah.

B
So, so in this point would be what? Designing, getting the idea about here?

S
Yeah.

B
Designing the experiment.

S
There and then testing.

B
Testing in here, so testing...

S
And refining and then like, then fact.

B
And your conclusion. Your results and conclusion up in here.

S
Yeah.

B
Ok, cool. So moving on from the imagination in the design stage, when we get the results, um, is it, do you think it's very clear what the results mean for experiments or is it often murky, or...

S
Um, it depends how good the testing was. If it's murky, you usually just start again, so it'd come back to...

B
Cycle back through the pattern.

S
Yeah.

B
And try and refine it.

S
And keep going until you get it really solid. Because you'll have your kind of murky, kind of factish, and you go, "Well this still isn't right, I wonder if..." and it goes again.

B
Yeah. So there's a cyclic process of...

S
Yeah. Until you get, I mean, that will keep going forever, cause like, as we said before, with new technology, we're going back and we might find something new that's going, I wonder if this is actually correct. It's always going, that's always going to go, that cycle. Imagination to fact, imagination to fact.

B
Yeah, ok. That's quite a cool idea. Is, cause you obviously sound like you're quite conversant with this, it's something that you've, I don't know if you've thought about it a lot, but you've kind of got a good grip on it for yourself. What's kind of influenced those, that view of science? Is it just something you've built up by doing it, or...

S
Yeah, it would just be something I've built up by doing it. I guess also for my love of it as well. Cause I never, at my old school, never had anything to do with science. You know, I had social studies, or like social science which is like, you know, thinking about the whale and how the whale works and stuff. But never had chemistry or physics or any of that cause we didn't have the facilities. It a was pretty basic school. English, maths, social studies. So having this opportunity to do science has been something I've loved. I love doing science, always wanted to do chemistry and stuff. Although, yeah, it's just because I, you know, haven't had the opportunity and I now have it, it's been kind of, what is this, kind of. I've had to actually, rather than just like, you know, if you had science when you were at your old school or whatever, you'd be like, ok, this is just kind of what we do. But because I didn't have that, I had to, like 2 years ago I had to think, well what is science? Because I never had the opportunities to kind of slowly become to it.

B
Right, that developing spiral that's in there.

S
Yeah. It was just suddenly there and I had to comprehend it.

B
Yeah. Were there certain things that helped you comprehend it, or?

S
I reckon, probably most of the teachers. Like in year 9 I spent a lot of time with Mr. Chisom who was my ?? teacher as well. So just having him talking to him about science things really kind of helped me understand science quite a lot more than, well, I didn't know really anything about it before. And it was so, ah, some of my friends here are quite sciencey and they've, are like, Connor and Lily, they did like science fair and stuff and so they've helped me quite a lot like socially and with all science.

B
Ok. So being able to interact with people that...

S
Know science.

B
...know it, and, yep. And you can kind of talk to them about it and go, "Oh, ok, this is what it is I'm trying to do."

S
Yeah.

B
Just earlier you mentioned that you'd always wanted to be a chemist.

S
Um, I just always wanted to do it. Not necessarily be it.

B
Become, yup.

S
But just, you know, you see in the movies and everything, all the like, test tubes, and I just always found that so fascinating how it works.

B
Yeah, yep.

S
So not necessarily being a chemist, but doing...

B
Having the opportunity to to do it.

S
To try it. Yeah. It's like, I wouldn't want to be a professional skydiver, but I would love to try skydiving.

B
(laughs) Good analogy. I like that. Yeah, ok. Cool. Um, so yeah, just totally distracted me with skydiving now. Um, if we go on to, um, well we've kind of talked about your influences then. So previously, um, like you've said at your last school you didn't have access to science. So really your knowledge of science had come from movies or things you'd seen?

S
I loved, I loved documentaries when I was a kid. I loved documentaries, you know, David Atinborough, all that. And I used to watch it all the time. Um, so that's where most of my kind of science knowledge came from. And you'd watch them and they're like showing you how they figured out a test, but because I didn't have that at school I wouldn't understand it, I kind of did understand it even though...

B
So you could kind of...

S
I got the idea of it, but I didn't understand it.

B
Yeah, yeah.

S
So yeah, lots of my kind of, background knowledge of science came from documentaries when I was a kid.

B
Yeah, yeah. You should see my room at home, I've just got banks of David Atinborough stuff, DVDs. My fiance doesn't like it, she thinks I'm a nerd. That's cool. Alright, so we've got a good idea here then about your influences, um, obviously the last couple of years being able to actually do science has formed that. Um, and that's helped build up your idea about the way science works and what it's doing. What I want to just move on to next is 3 particular terms that come up in science and just what your interpretation of what they mean and

how they fit together. So the first one is the term scientific law and what you think of when you come across that.

S
When I think of scientific law it's, I think it's something that's made... you know how they say that rules are made to be broken?

B
Yeah.

S
I think scientific law is kind of made to be broken. That it was like back when it made it was like, oh, you can't do this, you can't do that. They made scientific law, but then because they made scientific law, so many people went, "I want to challenge that." And they found so many new things and ways to do things. And then that just made the scientific law bigger. So as people challenge the scientific law, the scientific law grows.

B
Right. Ok, so it's kind of like a policing law.

S
Yeah.

B
It says you can't do this, which makes everyone go, oh, we're going to see if we can.

S
And then they do do it, and they go, oh, ok, you can do it, so the scientific law gets bigger.

B
Right. Ah, it encompasses...

S
It accepts that you can do it and gets bigger.

B
Right, ok, that's interesting.

S
And so you might find out, say like, they says before you can't mix this and this. And then you do that, and it goes, ok, so you can mix this and this, but you can't mix that with this. And people mix that with this and it gets bigger and bigger.

B
Right. So scientific law is a kind of definition of what we can't do in science.

S
But it's also a definition of what we can do.

B
Right. Ok, so, ah, ok, so...

S
It's what we can't do, what we can do, and what could be possible.

B

Right. So, so if we start off and we say, these are the things we can do. So scientific law says we can do this, scientific law says we can't do...

S
This.

B
Outside. And then every time we kind of push that boundary back.

S
Yeah.

B
And so if something swaps from being outside to something we can't do to something we can do...

S
What the can't, it's not necessarily, people say, it's like what we can do, but it's also what we could do. Or possibly do is probably better.

B
Yeah. So they could say it's not possible to mix these chemicals together to create something.

S
Yeah, yeah.

B
And then someone goes away and says, well actually, if I do this procedure and this and this...

S
So it's just the imagination and fact thing again. It's the fact is, you can't do this, and the imagination goes, but what if I could? And then they do it, and then it becomes fact that you can do it. And it gets bigger.

B
Yeah. Right, ok. So for you, your concept for the scientific law is it's a single, pretty much a single entity that encompasses all the things we...

S
Can do.

B
...we can do. And then we're constantly pushing it back to incorporate all the things.

S
Yeah. It's like, it's like a reaction that gets bigger, and it goes, ok, this can react with this, go, bigger, bigger, bigger.

B
Right, ok. Yeah, yeah, I've kind of, I've got that in my head there. So if we talk about a scientific theory then is another term, what does that?

S
That's kind of back to the imagination and the what if sort of thing again.

B
Yeah.

S
It's theory is going from, from the scientific law it's going, it's taking the rules that you can't break and going, well what if, what if I could break it?

B
Yeah.

S
And then trying to figure out a way to break it. That's kind of what theory is.

B
So theory's kind of that thinking about the ways I could get around this.

S
Yeah, like loopholes in the...

B
Yeah. So if I'm, if I'm, so you would use the word I'm theorizing about ways that I could get around this.

S
Yeah.

B
Yeah. Ok, um, just to, I'll put, possibly against that, or how you would interpret this differently. If we talk about, um, Darwin's theory of evolution, what does that then, how do you interpret that? That's a way of...

S
The theory of evolution is, well because science is such a, kind of, explanatory thing, it also clashes with religion quite a lot. The reason Darwin's theory of evolution is still a theory is because they still can't prove if God did it or not or if there is a God or not.

B
Right.

S
If someone was like, they managed to prove that it is or isn't something like that, then they can either call it fact or fiction.

B
Right.

S
That's why it's still, it's not the fact of Darwin's theory, of like, Darwin's evolutionary fact or whatever. That's why it's still a theory of evolution.

B
Right. So the crunch point for the evolution one is you've got to prove or disprove God.

S
Yeah.

B
Because either you need him or you don't need him. And then if you prove it one way or another, you need to have fact of evolution, fact of, say, intelligent design.

S

Yeah.

B
It's the count of measure. Um, again that's quite clear. If we use a different example instead of theory, talk about, um, Newton's laws of motion. They would mean what to you? The, the force equals mass times acceleration, those sort of...

S
Those, those are kind of, they're at the other end of the triangle. They're at the fact until they get proven differently.

B
Right.

S
Which I imagine eventually in bloody hundreds of millions of years, they could somehow. I mean there's no saying. You can't ever say, even though they do, you can't ever say something can't.

B
Yeah.

S
That's just back to the, the laws of...

B
Ok, so I'm thinking about your idea of what's inside law and what's outside law. So Newton's laws of motion are inside law partially because it's saying what they can do, but it's also outside law because it's saying, that means these things can't happen.

S
Yeah. There's like, kind of 3 rings of it. It's like kind of, the can't, the can, and the ones that say both.

B
Yep, yep. Yeah, ok, almost these ones act as the defining boundary as to if you're on this side of the line, these are the things you can do, if you're on that side these are the things that are saying we can't. And you're saying, pointing out that as we get more technology or as we get better at doing this we can start to push these things out more.

S
Yeah.

B
We start to sort of, using that Newton one of force equals mass times acceleration, it might be later we go, well, actually it's force times this proportion of mass, this proportion of acceleration, this proportion of something else and a number of things on there. Which means this actually is what's happening.

S
Yeah. It just floats in the air.

B
(laughs) Or we learn a way to make it float in the air by manipulating those things. Ok, that's cool. Um, one last one in terms of the definitions, because you're giving me lots of good stuff here. Um, scientific method, no we discussed scientific method, did we? No, so I'm getting confused with the interview I just had. The term scientific method, what does that bring up, or mean to you? Is it something you've heard, or?

S
Method is kind of a template for theories, I guess. For the imagination. It's more, the method is a way of doing it, like a method would be I hope this will work, what I think is like, you could say, a method would be, say, to boil something. It would be to get something to react with something. Method's kind of a, the only solid thing in the law, scientific law, as I view it. It's the only thing that won't, kind of, change.

B
Right.

S
And it's like something you can use, but you can't break.

B
Ok. Can you think of an example?

S
Like...

B
Do you ever use scientific methods, method yourself? Is it something that you encounter in school labs?

S
I think, not often really. If it is, I don't really notice it. But um, what I find kind of that it, my idea of it is that a method, yeah, a method is you can't, if you're going to boil something or, like, burn something, you can't not, burning it would be the method.

B
So you'd have to apply heat to get it to burn.

S
Yeah.

B
I couldn't pack it with ice and expect it...

S
Yeah, to burn. You can't, it's the only solid thing. You can't, well some things will get really hot in there if you put in reaction and stuff. But um, but that's still, it has to have heat to burn.

B
Right.

S
It can't get cold to burn.

B
Right, so the method is actually the procedure of things you have to do to make science happen.

S
Yeah.

B
Ok, yeah, yeah, cool. Sorry, it took me awhile to get on the same wavelength on that one. Ok, sweet. Um, just to finish off with the last little bit of the interview and I think I might even be going over, but that's ok. I'm sure you don't mind missing out on more science. Um, when we've gone through the questionnaire, you'll recognize this, this is your, the one you did, we had some certain questions that didn't kind of pop out in the

way that we expected, didn't line up. And so one of the things we're just doing is going through with students to see how they interpreted it all, what they thought about it. Um, so one of the first ones, question number 8 was one which we weren't too sure on. So past explanations do not affect new explanations. Um, you disagreed with that, so to your mind, whatever I've been thinking in the past is going to affect, or influence the way I think about the new stuff? Is that you think by that, or what did you?

S
The past explanation, um, wait, hang on, it was the wording.

B
Do not affect... So what it's saying is, whatever we've thought about how this works in the past, that's not going to influence if we come up with a new theory?

S
It's not... It's like you're going back, it's going back and going, ok, I'm going to change it. I think this is wrong and I'm going to change it. And if they do prove it wrong, you can't go, yeah, but back here they said you couldn't. But it's like, but it's been proven wrong, you can't go, because it was proven wrong, back then when they didn't have as much technology.

B
Right, ok.

S
So they could...

B
Um, so you can't, if you get new evidence, you can't go back and say, well, the old explanation is still the right one, even though the new evidence...

S
Yeah. You can't, you can't do that.

B
Does the type of explanation you come us with after you've got your new evidence, is it going to be based on what, the way people were thinking before?

S
It's going to be based on whatever new evidence you have.

B
Right. So it, it's solely based on the evidence.

S
Yeah. On what you have. You can't go...

B
So you just follow the evidence.

S
Yeah. Otherwise it wouldn't, it wouldn't be the fact, I guess.

B
Yeah.

S
Or the, yeah.

B
So each new time you get the evidence you should stop, you look at it fresh, and you go, what does this mean? It means this. And then if you look back and that was the old answer that's fine, you carry on the same way. But if it's a different answer you go well, that's wrong, this is the new way.

S
Yeah.

B
Yep, ok, cool. That kind of clarifies that one. Um, if we just flip over to, um, number 15. Um, scientific data can be interpreted in many different ways. And you were happy with that?

S
I think that some people, like it could be interpreted because you go, well this means this, but then someone else will go, but it actually means, like it also means this.

B
Right.

S
Like saying, um, kind of, you know, which which is which. It can be interpreted in lots of different ways.

B
Yep, yep. I get that one. (laughs) It's a nice little analogy again. Um, so the different interpretations, are they distinct? Or could they be competing against each other?

S
Most of the time, if they do compete, then they go, it goes back to the imagination and they do the test again and see what happens. But...

B
Until you come out with a clear...

S
Yeah, which one is which, which which is which. Um, but others, otherwise I would go, ok, so this means this in this part, and in other parts you would go, but it also means this.

B
Right.

S
They would then go, that's ok, like a tree. They would go, ok, I found this...

B
So you're actually branching explanations.

S
Yeah, and then they go, two different tiers, and then that will, you know.

B
So the same phenomenon could actually be looking at 2 distinct things.

S
Yeah.

B
Or the same experiment could be looking at 2 different phenomena.

S
Even though one person, even though the person who made the test doesn't realize it, they could actually explain something else by the test.

B
Oh, right, so just by pure chance, I've actually stumbled across something else.

S
So you go, ok, so this is how grass works and the go, and then another one comes along and goes that's also how leaves work. And so it kind of...

B
Snow-, and branching off from each other. Ok, yep, yep, I see where you're going on that one. Cool. Um, ok then, which other ones do we have... question 16. Scientific evidence only includes data from the world around us. Um, this has caused some real problems. And I see you just decided to hang in the middle. (laughs) What did you think when you saw that question? What did you think we were talking about?

S
The world around us, I was like, earth, are they asking earth? Or are they asking what we know?

B
Right.

S
Cause the world around us can be the whole, like massive, infinitely stretching universe.

B
Yep.

S
Or it can just be earth.

B
Yeah, yeah.

S
So...

B
In that case it just wasn't clear as to what...

S
Yeah.

B
I know it's not just earth, I'm assuming that earth...

S
But it could just be earth.

B
Yeah. So in terms of this question, it might be or might not be. In terms of what you think science does, science does actually go beyond the internal...

S
Yes.

B
Ok. So if we change that to that it includes data from everywhere, you would go...

S
Well, that's everywhere. That's everywhere it's being made it's the universe, it's infinitely expanding. Until it gets to a maximum point and creates the gnuba nap. Opposite of the big bang, Hitchhiker's Guide to the Galaxy.

B
There you go. And you can go to the restaurant at the end of the universe. Um, ok, cool. Um, so, so that one clearly, that's a question of the wording of what that meant. Um, what's another one we were looking at. So in terms of 18, there is not single scientific method. Um, we kind of alluded to that before when we were describing scientific method.

S
Yeah, there are lots of different ways to test for something. There's not just, you can't, there's not just heat. You can't just heat something to get it. You can, well, you can just heat something to burn it, but there's no single kind of way to find out something.

B
Yeah, there's a battery of tests I can do on something.

S
Yeah.

B
Each of those is a different method. Yep, ok, that's cool. I think 22 is actually just the same sort of thing. Scientific method refers to all the steps scientific methods follow. So, in that case it doesn't really... Yeah, that's kind of where you're going on that one. Alright. So just to sum up then, just to finish in the last few minutes since I've kept you away from science for so long... Um, since we've been discussing this, is there anything else you'd say about science itself or what scientists do?

S
Science is, I still reckon, just knowledge. It's just, what science is is what science is. Learning what is, I guess is the way I'd put it. And that's still...

B
Yeah, that's quite nice, what is as opposed to what isn't.

S
Yeah.

B
That's sort of, yeah. Almost checking what...

S
They do, they do search what isn't. But that's always, as they say, always changing. What isn't is always changing. That's why they're searching what is. Like you can't say water's actually grass, because water is water.

B

Yeah, yeah. Ok. Ok, cool. I don't think there's anything else I want to know on that. Thank you very much for your assistance on that.