

**Science and Mathematics Education Centre**

**The effectiveness of introducing “The Nature of Science” strand into  
the New Zealand curriculum with regard to increasing student  
engagement in science**

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**This thesis is presented for the Degree of  
Doctor of Science Education  
of  
Curtin University**

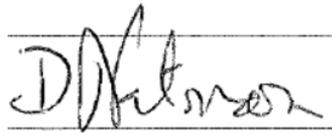
**March 2017**

## DECLARATION

To the best of my knowledge and belief, this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for any other degree or diploma at any other university.

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Date 28/2/2017

## **ABSTRACT**

Capturing the interest of students in science is seen as vital to the welfare and prosperity of most modern societies in order to produce a scientifically literate population able to cope with life in the 21<sup>st</sup> century. Today's students are living in a world of rapid technological and environmental change and need to be able to work collaboratively while thinking critically and creatively to solve problems. In New Zealand, as in many other countries, one response to both fostering these key skills and encouraging students to choose senior science subjects has been to raise the importance of Nature of Science (NOS) in the science curriculum. Teachers are expected to use NOS concepts to deliver traditional science content knowledge, with the expectation that by understanding how and why science works, students will see the relevance of what they are studying and gain the desired thinking skills.

The problems implementing many well intentioned curriculum reforms in science have been well documented, with many producing little change in teaching pedagogy or student learning outcomes. Many studies, too, have revealed effective strategies for delivering NOS but have also shown great resistance on the part of teachers to change their practice and consistently use these successful techniques. This thesis aims to investigate the link between teaching with a NOS approach and the engagement of students in science classes. If it can be shown that using a NOS approach does improve the engagement of students, this could encourage more teachers to use these strategies, thereby fulfilling the twin goals of improved scientific literacy in the general population, and increasing the number of students choosing to study science subjects at higher levels.

The case study undertaken involved two Year 9 cohorts in successive years at a large co-educational high school in New Zealand, where the new science curriculum emphasising NOS had been introduced. The teachers' views about NOS were first ascertained, and a shared vision concerning the importance of NOS created in the school, using the research results. Students in both years were surveyed and interviewed to see if their attitudes towards science changed as a result of their classroom experiences. Finally, lessons were observed and teachers and students

interviewed to discover if NOS ideas were actually being delivered in the classroom, and if so, did the inclusion of NOS increase the engagement of the students.

The results indicated that teachers did understand and value NOS concepts and were keen to implement them in their lessons. However, some teachers struggled to find appropriate activities and resources to teach NOS, but once given some support and direction were positive about their effect on student engagement. All the lessons observed did include some NOS themes, but most of these were implicit. Even so, the response from the students was very positive, with increased behavioural, emotional and cognitive engagement noted.

The research suggests that incorporating NOS into a Year 9 science programme can improve the engagement of students, but that this requires considerable professional support and development of the teachers. Merely including NOS in curriculum documents is not sufficient to produce change in the classroom. However, once teachers can see the benefits of including NOS and have the strategies and resources to deliver NOS, they are willing to put in the extra time and energy needed to change their teaching pedagogy. The benefits of teaching with a NOS approach include producing happy, less disruptive and more engaged students, who in many cases show improved understanding of science content knowledge. These positive outcomes suggest that teaching with a NOS approach is feasible and effective, and is therefore a strategy that more schools and teachers should adopt.

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## List of Abbreviations and their meanings

ACARA	Australian Curriculum Assessment and Reporting Authority (ACARA, 2013). An Australian government organisation responsible for developing and implementing the national curriculum for schools, as well as creating national assessments and reporting on the performance of students and schools.
ATSSA	Attitude Toward Science in School Assessment (Germann, 1988). A fourteen item Likert-type questionnaire designed to measure student's feelings towards science lessons.
BSCS	Biological Science Curriculum Study (Bybee et al., 2006). A non-profit organisation with the aim of producing scientifically literate citizens by developing high quality resources for science teachers.
CSEV	Chinese Scientific Epistemological Views (Chai, Deng & Tsai, (2012). A Likert-response instrument consisting of 25 items designed to measure five dimensions of students' views about NOS and the epistemology of science.
DfEE	Department for Education and Employment (DfEE/QCA, 1999). Government department in the United Kingdom responsible for producing school curricula in the 1990s.
HSTP	High School Transformation Project (Lederman & Lederman, 2012). A large scale professional development project in the Chicago area to improve teaching and learning of science with the aim of improving student achievement and understanding of science.
ICAN	Inquiry, Context and Nature of Science (Lederman & Lederman, 2012). A large scale professional development project for K-12 science teachers in the Chicago area designed to improve teaching and learning about NOS and scientific inquiry.
IPI	Instructional Practices Instrument (Valentine, 2005). A rubric and methodology to enable consistent judgements about the level of cognitive engagement of students while making classroom observations.

LISP	Learning in Science Project (Bell, Kirkwood, & Pearson, 1990). A series of projects carried out at the University of Waikato to investigate how to improve learning in science classrooms.
MCEETYA	Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA, 2008). An Australian government organisation founded in 1993 to provide policy advice on the development of a new curriculum.
KNOWS	Knowledge of the Nature of Whole Science (Allchin, 2011). Assessment tasks for NOS based around contemporary or historical contexts.
NCEA	National Certificate of Educational Achievement (Hipkins, 2013a). The qualifications obtained by senior secondary school students in New Zealand.
NGSS	Next Generation Science Standards (NGSS Lead States, 2013). A framework describing teaching and learning outcomes for K-12 students in the United States of America.
NHMRC	National Medical and Health Research Council (NHMRC, 2007). An Australian government organisation set up to promote high standards of research in health related fields, including ethical dimensions.
NOS	Nature of Science (Lederman, 2007). Explanations of the way in which science works. An understanding of how and why scientists follow particular methods and reach conclusions.
NOSS	Nature of Science Scale Kimble (1967). A Likert-response instrument consisting of 29 items designed to measure scientists', teachers' and college students' views of NOS.
NRC	National Research Council (NRC, 2012). An organisation in the United States of America with the aim of increasing the public understanding of science, technology and engineering, and improving public policy making in these areas.
NSKS	Nature of Scientific Knowledge Scale (Rubba & Anderson, 1978). A Likert-response instrument consisting of 48 items designed to measure six dimensions of students' scientific literacy.

PARSEL	Popularity and Relevance of Science Education for Scientific Literacy (Freire, Faria, Galvao, & Reis, 2013). A European Union project to improve teaching and learning of science in schools by creating a community of educators that develop and share best practice strategies.
PCK	Pedagogical Content Knowledge (Abd-El-Khalick & Lederman, 2000). The knowledge acquired by teachers that enables them to deliver the content of lessons effectively.
QCA	Qualification and Curriculum Authority (DfEE/QCA, 1999). A non-departmental organisation in the United Kingdom with the responsibility for maintaining and developing the national curriculum.
ROSE	Relevance of Science Education (Jenkins & Nelson, 2005). An international comparative research project collecting and analysing information about science and technology from the viewpoint of the learner.
SBR	Scientifically Based Research (Denzin, 2008). A requirement in the United States that professional development programmes for teachers should be based on sound educational research.
SI	Scientific Inquiry (Lederman, 2007). The processes involved in carrying out an investigation in science, including such steps as planning, collecting and analysing results and making conclusions.
SINOS	Students' Ideas about Nature of Science (Chen et al., 2013). An empirically based Likert-response instrument consisting of 47 items designed to measure seven dimensions of younger students' beliefs concerning NOS.
SLH	Science Learning Hub (Chen & Cowie, 2014). An online resource created to support science teachers in New Zealand.
STEM	Science, Technology, Engineering and Mathematics (Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). An acronym used to describe education or research in the named fields.

TIMMS	Trends in International Mathematics and Science Study (Caygill, Kirkham, & Marshall, 2013). A large scale, comparative study of content knowledge, thinking processes and attitudes towards mathematics and science of students in fourth and eighth grade around the world, run every four years.
TOSRA	Test of Science Related Attitudes (Fraser, 1978a). A Likert-response instrument consisting of 70 items designed to measure five dimensions of school students' attitudes towards science, ranging from enjoyment of science lessons to the adoption of scientific attitudes.
TOUS	Test for Understanding Science (Cooley & Klopfer, 1963). A sixty item multiple-choice test designed to probe student understanding of science in three broad areas; the scientific enterprise (science and society), scientists and the methods and aims of science.
UNESCO	United Nations Scientific Educational and Cultural Organisation (Staver, 2007). A specialized agency of the United Nations with the aim of promoting peace and security throughout the world.
VNOS	Views of Nature of Science (Lederman, 2007). An instrument designed to illicit views on the nature of science through written responses to open-ended questions. There are several versions available for use with different groups such as elementary students or teachers. These are labelled VNOS-A, B, C, D or E.
VOSTS	Views on Science-Technology-Society (Aikenhead & Ryan, 1992). An instrument developed to measure high school students' views on NOS using context based items requiring students to choose from a range of possible responses.
5E Instructional Model	Engagement, Exploration, Explanation, Elaboration, Evaluation (Bybee, 2009). A method of teaching designed to promote conceptual change in science developed by the Biological Sciences Curriculum Study (BSCS).

## **CHAPTER ONE Introduction**

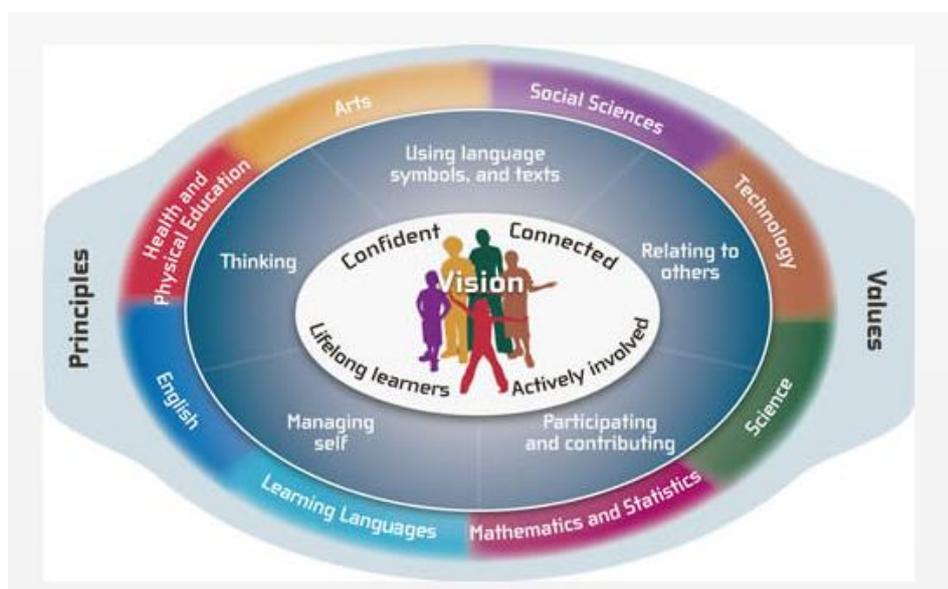
### **1.1 The road to research**

Over the twenty-five years of my teaching career, I have always aimed to make my lessons interesting and relevant to my students. I love learning about new discoveries and applications of science, enjoy the marvellous complexity and beauty of the natural world, and endeavour to pass on this sense of wonder and excitement. In 2004, I was appointed as Head of the Science Faculty at the High School where the current research project has been based, and began promoting this vision of science teaching and learning through the catch phrase, “Science is Fascinating and Fun”. I initiated and promoted many science-related activities outside the regular curriculum, such as an after-school Science Club, numerous competitions, and exciting trips taking students to the Space Camp in Alabama, and Great Barrier Reef. My approach to science teaching has always had a focus on the engagement of students, and I knew that one way of achieving this was to include lots of experiments and practical work in my lessons.

At the same time as I was taking on the challenge of increasing the participation of students in science and encouraging my colleagues to fully engage their students, the New Zealand Ministry of Education was developing a new national curriculum across all subjects. It was reasoned that schools needed a curriculum written for the 21<sup>st</sup> century, which fostered creativity and promoted lifelong learning for the new ‘knowledge’ age. As Karen Sewell, Secretary for Education, put it in the forward of the curriculum document (Ministry of Education, 2007a, p4): “It [the curriculum] takes as its starting point a vision of our young people as lifelong learners who are confident and creative, connected, and actively involved.” This active involvement strongly implied that full engagement of students with their learning was an important objective.

Significant consultation was undertaken throughout the country and input into critiquing and developing the draft curriculum was encouraged. The draft was released in 2006, the final document in 2007, with full implementation required by 2010. During this period, there were whole staff and department meetings to analyse

the new curriculum and work out how it could be integrated across the school. The vision and values described in the curriculum are summarised in Figure 1.1. These were compared with the values already in place at the school, and ways of integrating these into classroom practice, along with the ‘key competencies’, were formulated.



*Figure 1.1*

Diagram summarising the ‘front-end’ of the new NZ curriculum in the 2006 draft (Ministry of Education, 2006, p7). Key competencies are placed in the middle ring, between the vision and learning areas.

In science, the major change was the increased emphasis of the Nature of Science (NOS) strand, through which all the science content was to be delivered. This emphasis on NOS came as a surprise to me, although as discussed in Section 3.2.2 NOS had appeared in curriculum documents since 1993. Although there appeared to be little change to the actual content taught in science, there seemed to be a genuine attempt to fundamentally change the way science was delivered in the classroom with NOS the driving force for this change.

The intent of the new curriculum was well summarised in the overall vision described at the start of the document (Ministry of Education, 2007, p8): “Our vision is for young people: who will be creative, energetic, and enterprising; who will seize the opportunities offered by new knowledge and technologies to secure a sustainable

social, cultural, economic, and environmental future for our country.” In order to find out what this vision looked like in New Zealand, I applied for and gained a Royal Society Science, Mathematics and Technology Teacher Fellowship (The Royal Society of New Zealand, 2002) to work at Syft Technology Ltd. for the whole of 2009. This company epitomised both the vision of the overall curriculum and NOS in the 21<sup>st</sup> century. Syft Technologies made an instrument able to detect volatile organic compounds, in real time at concentrations as low as a few parts per trillion (Syft Technologies, 2004).



voice200™

- Precision analytical mass spectrometry instrument
- Instantaneous identification and quantitation of Volatile Organic Compounds (VOCs)
- Real-time detection down to low level pptv
- Analysis of whole-air and headspace samples in seconds
- Ease of operation with push-button simplicity and no sample preparation
- Suitable for operation in commercial, industrial and research environments

*Figure 1.2*

Extract from Syft Technology data sheet on the Voice200™ (Syft Technologies, 2014).

This amazing machine, shown in Figure 1.2, was developed from scientific research carried out by Professor Murray McEwan at the University of Canterbury studying the mechanisms of organic reactions in inter-stellar dust clouds (McEwan, Scott & Anicich, 1998; Milligan, Wilson, Freeman, Meot-Ner, & McEwan, 2002). Working at Syft enabled me to see the importance of teaching both the skills and content knowledge required for such a high-tech enterprise, as well as the way science interacts with the commercial world to make this type of project viable. The groups of experts (scientists, engineers, software developers, sales and marketing team) had to work together to make a successful company, perfectly illustrating the rationale behind the new curriculum and NOS.

During my time at Syft I was able to examine my own views on NOS and science teaching and read widely in both the research (Claxton, 2006; Hattie, 2003) and popular science literature (Bryson, 2003; Hooper, 2008). I attended a number of conferences and was fortunate to meet Sir Paul Callaghan, a scientist who was passionate about the ability of science to lift New Zealand's economic performance. His arguments in the book, *Wool to Weta* (Callaghan, 2009), supported the vision of the new science curriculum, and helped convince me to make real changes in the way science was taught. I returned to my school in 2010 and set about re-writing topics for Year 9 and 10 science, to try and incorporate ideas from the curriculum and NOS. For example, the traditional topic on 'Matter' was re-named 'Fabulous Fragrances', and required the students to create a fragrance of their own while learning about the particle theory of matter.

In the spirit of teacher inquiry promoted by the new curriculum, I decided to undertake the current research project with Curtin University. First, I wanted to improve my knowledge on teaching pedagogy and find out if the latest educational research did support our new curriculum. Second, I wanted the tools to carry out teacher inquiry in order to analyse whether the changes being made in the Junior Science programmes were making any difference to the engagement and learning outcomes of students in the classroom. So, my road to research eventually led me to investigate the link between NOS and the engagement of students in science classrooms, as described more formally in the next section.

## **1.2 Rationale for the research**

Capturing the interest of students in science has been seen as vital to the welfare and prosperity of most modern societies (Obama, 2009; Prime Minister's Science Advisory Committee, 2010). Scientific and technological innovation have been the driving forces behind the progress of countries in the 20<sup>th</sup> century, and many politicians and decision makers believe that they will be even more important in the 21<sup>st</sup> century. In New Zealand, Sir Peter Gluckman was appointed in 2009 as the first ever Chief Science Advisor to the Prime Minister and has been active in promoting both the role of science and science education in lifting the productivity of the country (Gluckman, 2009, 2011, 2013b). He has strongly emphasised the need to

increase the engagement of students with science in order to increase the number of students continuing onto science-related careers.

Unfortunately, concerns have been raised around the world that there are not enough people entering science and technology related careers (Fensham, 2008; The Royal Society, 2014). In a comprehensive review of the international literature Tytler, Osborne, Williams, Tytler, and Cripps Clark (2008) concluded that major changes were needed in teaching pedagogy in order to improve the engagement of students with science in schools, and hence encourage them to continue onto science careers. This view was supported by Bolstad and Hipkins (2008), who described low levels of engagement in science across the middle school years in New Zealand.

The New Zealand Curriculum (Ministry of Education, 2007a) was produced to prepare students for life in the 21<sup>st</sup> century, and Hipkins (2012) described how this aim was applied when writing the science curriculum. The curriculum document drew on educational research (Hattie, 2003; Millar & Osborne, 1998) with the intentions for science well summarised in the concluding remarks of Barker, Bartholemew, and Hipkins (2004, p.10): “We need, therefore, to create a space for competencies that students find meaningful and motivational while they are at school, and which reflect a view of science and science education that is appropriately expansive, socially integrated and future-focused”. The result for the science curriculum in New Zealand was the introduction of a learning strand called NOS, which the Ministry of Education (2007a, p. 28) described as follows:

The Nature of Science is the overarching, unifying strand. Through it, students learn what science is and how scientists work. They develop the skills, attitudes, and values to build a foundation for understanding the world. They come to appreciate that while scientific knowledge is durable, it is also constantly re-evaluated in the light of new evidence. They learn how scientists carry out investigations, and they come to see science as a socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions.

This description of NOS summarises much of the educational research on the subject. McComas, Almazroa and Clough (1998) for example, produced a list of science objectives drawn from international curriculum documents which showed a clear consensus about the nature of science. Osborne et al. (2003a) conducted a Delphi study of experts in the science community and produced a list of key elements required in any curriculum delivering NOS, again with a remarkable degree of consensus between the participants. Views from these studies, and others such as Aikenhead and Ryan (1992), Lederman (2007), and Deng, Chen, Tsai, and Chai (2011), fitted well with the vision of NOS as described in the New Zealand Curriculum.

In a report examining the state of science education in New Zealand (Bull, Gilbert, Barwick, Hipkins, & Baker, 2010), the authors suggested that one way of improving the engagement of students in the middle years of schooling was to build on the NOS strand in the curriculum. They argued that when students explored scientific issues and processes that were relevant to them, learned how scientists work and used critical thinking skills, they became more engaged in science. In their report entitled *Engaging Young New Zealanders with Science*, The Prime Minister's Science Advisory Committee (2010) supported this view.

However, including a strand such as NOS, in a curriculum document does not necessarily mean that teachers in the classroom deliver the stated NOS objectives. Van den Akker (1998) described several levels of curriculum representation, starting with the ideal curriculum containing the underlying vision, going through stages such as the perceived curriculum, and concluding with the attained curriculum, the learning outcomes of students. Looking at curriculum reform and implementation around the world, van den Akker (1998, p 443) observed "it is naive to expect much from top-down strategies of curriculum reform". This is a view shared by many directly involved in NOS research and implementation (Fensham, 1985; Lederman, 2007; McComas et al., 1998). In fact, McComas et al. (1998, p. 514) went so far as to state, "After almost 50 years of interest concerning the nature of science in science curricula, little change has occurred."

In order to establish whether the NOS strand in the curriculum does have an impact on student engagement, the concept of ‘engagement’ itself needs to be explored. Bull Gilbert, Barwick, Hipkins, & Baker (2010) pointed out that measurements concerning student engagement range from attendance data (students are physically present and therefore engaged in learning) to school grades, subject and subsequent career choices. In a review of the literature on students’ attitudes towards science (Osborne, Simon, & Collins, 2003b), also found a wide variety of measures had been used to establish levels of student attitudes and engagement, including questionnaires, subject inventories and interviews.

An analysis of engagement was offered by Fredericks, Blumenfeld, and Paris (2004), who described three important components of engagement; behavioural, emotional and cognitive. Ideally all three components should be observable in classrooms and their relative effects measurable, although it was acknowledged that this is a difficult and complex task. Pugh et al. (2010) argued that deep engagement in science occurs when students undergo a transformative experience and begin to apply their in-school learning to their everyday lives. Eccles and Wigfield (1995) explored the concept of ‘task value’ and the factors within this that lead to students being motivated to value what they are learning. Task value consists of three factors: interest, importance and utility. All three have strong connections to NOS as students need to appreciate the use of the tasks required of them, both for achievement of short term goals and to take their place in society. This may be through science based careers or realising that the knowledge they gain can help them make informed decisions about scientific issues that affect their lives. This view of engagement appears to capture the intent of the developers of the New Zealand Curriculum.

There are many studies in the research literature which investigate the way NOS is taught and the subsequent level of NOS understanding gained, with comprehensive reviews of these produced by Lederman (2007) and Deng et al. (2011). Some of these studies report that student interest and engagement in science increases as well as NOS understanding, although this may not have been the initial focus of the research. For example, using the history of science as a teaching strategy has been investigated by several researchers, with Kim and Irving (2010) reporting positive attitudes towards science from students during post-intervention interviews. In

another study where student-centred learning was used to reflect the ways in which science works, more positive attitudes towards both science classes and science careers was reported (Akçay & Yager, 2010). A third strategy shown to improve NOS concepts is teaching through argumentation, with Dawson and Venville (2010) reporting that during science lessons observed using argumentation, the students were engaged and on task. These studies indicated that there was a link between NOS and engagement which is the focus of my research project.

### **1.3 Setting and participants**

This study was based in one large co-educational secondary school in Christchurch, New Zealand. The school draws the majority of students from its immediate neighbourhood, with a cross-section of socio-economic and ethnic groups represented. Students are placed in Year levels from 9 to 13, with Science a compulsory subject in Years 9 to 11. The Science Faculty consists of a mixture of eighteen full- and part-time teachers. The study was spread over three years with a focus on Year 9 classes in 2013 and 2014.

### **1.4 Research Questions**

To enable the overall aim of this thesis to be investigated, three key research questions were formulated:

1. How effective is the Nature of Science strand in the NZ Science curriculum in terms of engaging Year 9 students in a New Zealand high school science programme?
  - 1a. What are teachers' perceptions of the effectiveness of the Nature of Science strand in terms of engaging Year 9 students in high school science classes?
  - 1b. What are Year 9 students' perceptions of the effectiveness of the Nature of Science strand in terms of engaging them in high school science classes?
2. What teaching strategies are being used to deliver the Nature of Science to Year 9 students and what impact do these NOS strategies have on student engagement?

3. What are the teachers' views of NOS and have they changed as a result of implementing a new curriculum?

3a. Has the Nature of Science, as an overarching strand been genuinely incorporated into the day-to-day teaching of science?

### **1.5 Overview of methodology**

The research project focused on a single school, and more particularly the teachers and students involved in Year 9 science classes. The methodology, case study, was well suited to this setting and set of research questions, with a full description of the methods used detailed in Chapter 4. Creswell (2008) described a case study as an in-depth exploration of a bounded system often used to illustrate a particular issue, such as engagement in science. Anderson (1998) pointed out that most case studies are interpretive and seek to analyse a particular phenomenon in a natural setting, such as school science laboratories. This research project was grounded in the constructivist-interpretive paradigm, as the knowledge gained came from trying to understand the situations students and teachers encountered from their own perspectives. A major purpose of this research was to point out to teachers what works in the classroom and Cohen, Manion, and Morrison (2011) recommended case study methodology as a good way of achieving this goal.

In a review of the literature on measuring attitudes towards science, Osborne et al. (2003b) acknowledged the difficulties in measuring attitudes to, or engagement with school science as opposed to science in society. Many different instruments have been used with the most reliable results coming from a mixed methods approach using both quantitative and qualitative techniques. Therefore, the first research question was addressed using a questionnaire supported by interviews. A well-established tool to investigate attitudes in science is TOSRA (Test of Science Related Attitudes), developed by Fraser (1981). This instrument uses a Likert scale set of responses to produce quantitative data that can be statistically analysed. The TOSRA instrument was chosen because its validity and reliability has been well established through its use in many studies (Blalock et al., 2008; Haladyna & Shaughnessy, 1982).

The TOSRA survey was given to students in 2013 and 2014 to enable two different Year 9 cohorts to be compared, providing a greater depth of data. Semi-structured interviews were then carried out with a total of twenty-one students using key questions that emerged from the questionnaire data, a form of triangulation that added validity to the data (Mathison, 1988). In addition to the data collected directly from students, ten teachers of the classes surveyed were interviewed concerning the TOSRA information about their students. This provided another check on the validity of the student data. More detail regarding the steps taken to ensure the reliability and validity of the data are described in Section 4.9.

The second research question required cycles of observation, interview and reflection with a selection of teachers and classes in order to build rich descriptions and an understanding of the factors that engaged students. Teachers at the school had been exposed to NOS ideas and strategies through in-house professional development since the introduction of the new curriculum, and continued to apply and develop these over the course of the study. The observations and interviews were used not only for this research project, but also to provide feedback to teachers concerning the strategies which were effective in improving both NOS concepts and engagement in science.

The third research question was tackled using the Views of Nature of Science (VNOS) questionnaire (Lederman, 2007), followed by interviews with the teachers. In a comprehensive review of research on VNOS, Deng et al. (2011) noted that questionnaires backed up by careful interview techniques provided a reliable way of determining teachers' views of NOS, and therefore was the approach taken in this research project.

Thus the research used a mixed methods approach in order to collect data appropriate to each of the research questions, as recommended by Onwuegbuzie and Leech (2005). This enabled triangulation (Mathison, 1988) through the use of different sources at different times adding to the validity and reliability of the data.

## 1.6 Significance

This research is significant as it examines the effect of teaching with a NOS approach on the engagement of students with school science. As discussed in Section 1.2 the need for improved engagement in science has been a concern in many countries for some time, especially during the transition from primary to secondary schooling (Speering & Rennie, 1996). However, there has been little research to investigate possible links between NOS and engagement. If it can be shown that teaching with a NOS approach does increase engagement, this would be a powerful motivator for teachers to change their practice and integrate NOS into their regular lessons.

A great deal of educational research has been carried out concerning NOS and its impact on science teaching in schools. Lederman (2007) argued that after 50 years of research on students' and teachers' conceptions of NOS, most researchers and governments agreed on the benefits of including NOS in curricula, but that teachers still struggled to see the value of committing time to NOS in their classrooms. This view was re-enforced in a project (Spiller & Hipkins, 2013) in which educational researchers worked with two New Zealand secondary science teachers to implement new teaching strategies in line with both the NOS ideas and overall intent of the new curriculum. Even though the teachers recognised the effectiveness of the strategies, they soon returned to their familiar, more traditional teaching techniques after the project concluded.

Meanwhile, research on engagement has also developed considerably over the last thirty years. There are now sophisticated theories to explain how and why students become engaged with their learning and there is agreement on the crucial importance of engaging students in school (Newman, 1992; Reschly & Christenson, 2012). Fredericks et al. (2004) noted that there was considerable research evidence linking engagement with improved learning outcomes for students. They called for more qualitative research on engagement in classroom settings so that information about how and why interventions to improve engagement work or not could be gauged. This project addresses this need, specifically looking at the effect of NOS teaching on engagement in the classroom.

Although some previous studies have looked specifically at science strategies that impact on student engagement (Bybee, 2009; Olitsky & Milne, 2012) there has been very little research on how teaching with a NOS approach affects engagement. The current research helps gauge the effectiveness of the new curriculum and investigates whether the considerable effort expended by teachers to include NOS does make a difference to student engagement. The information gathered has already been used at the school where the research was carried out as the findings were continuously fed back to individual teachers and the science faculty as a whole, as described in Section 4.2. Given the difficulty of changing individual teacher practice (Spiller & Hipkins, 2013; Tobin & McRobbie, 1997) this study examined a model of introducing NOS at the level of a whole science department which may prove useful to other schools within New Zealand and further afield.

### **1.7 Limitations**

This study involved only one secondary school and so extrapolation of the findings to other settings would have to be treated with caution. However, the science content and teaching environments are typical of many schools in New Zealand and around the world, as I have directly observed myself from over 25 years of teaching experience, including in New Zealand, the United Kingdom, and the Caribbean. Shulman (1997) acknowledged generalisation as a problem for all types of research, but particularly so for case studies in the interpretative paradigm. Can the analysis of just one researcher in one school provide any meaningful outcomes, useful to any other situations? As Guba and Lincoln (1989) stated, to be transferable, research must employ the technique of rich description, whereby enough data is presented to convincingly support interpretations made. The current research has aimed to achieve that goal, so that the findings may indeed be useful for science teachers, and those involved more widely in science education.

### **1.8 Thesis overview**

This thesis investigates the effect of teaching with a Nature of Science approach on the engagement of students in the first year of post-primary science education.

An overview of the literature concerning NOS is contained in Chapter 2. The way NOS has evolved and been defined at various times is significant for its subsequent introduction into many science curricula around the world. For example, the differences between Scientific Inquiry (SI) and NOS are still a source of confusion for some (Lederman & Lederman, 2014). Given the importance attributed to NOS as a way of improving science literacy and other outcomes, the development and use of instruments to measure both teacher and student views around NOS is also described. Finally teaching strategies purported to better deliver NOS are examined.

Chapter 3 explores the literature concerning student engagement and curriculum implementation. Much research concerning engagement of students in school has been carried out, with several studies particularly focusing on science education. The definitions and types of engagement, such as behavioural, emotional, and cognitive, are described. Another important factor is the relationship between attitudes to science and engagement in science lessons, which raises the issue of how engagement can be measured. Examples of how these matters are approached from around the world are explored.

The final section in the literature review presented in Chapter 3 concerns curriculum implementation, and provides a brief history of the process in New Zealand and a selection of other countries. How curriculum writers manage the many competing objectives, such as training future scientists or equipping citizens for their role in a democratic society, is crucial to understanding how the final documents are presented to teachers. Another issue that arises whenever a new curriculum is produced is how much training is supplied for teachers, and the level of resources provided. All these factors affect the way NOS is delivered in the classroom and experienced by the students.

Chapter 4 describes the research methodology, including details of the programme setting, participants and research instruments. The application of quality standards and steps to ensure a sound ethical approach are also explained. Chapters 5 and 6 present the results from data collection and analysis of their significance. The interpretation of the results, relevant conclusions and suggestions for further study are made in Chapter 7.

## **CHAPTER TWO Nature of Science literature review**

### **2.1 Introduction**

There is a vast amount of literature available about the nature of science (NOS) stretching back over the last hundred years or more, with contributions from science educators, historians and philosophers of science, as well as scientists themselves. Several major reviews of this literature have been conducted (Deng et al., 2011; Lederman, 2007; Lederman & Lederman, 2014) which summarised the various components of NOS and why it is important for students, scientists and the general public to know about NOS. However, it is only very recently that a connection between NOS and engagement of students in school science has begun to appear in the literature (Allchin, Anderson, & Nielsen, 2014; Forbes & Skamp, 2014). This review re-examines material concerning NOS, constantly seeking clues from the past to help understand why including NOS in schools might help engage the students of today.

If using NOS to engage students is an effective strategy, then science teachers need to have a good understanding of NOS, just as it is expected that chemistry teachers have a good understanding of chemistry. However, many researchers have found that not only science teachers, but many scientists, have limited understanding of NOS (Kimble, 1967; Lederman, 2007). An examination of the literature to see how ideas about NOS have developed over the last hundred years may help explain why teachers today have difficulty with the concept, and suggest ways in which their knowledge can be improved.

Once the major questions concerning the possibilities of using NOS to engage students, and the origins of teacher views about NOS have been examined (Section 2.2), this literature review focuses on three specific areas. The first, Section 2.3, deals with the distinction between Scientific Inquiry (SI) and NOS, as there has been much discussion over the definition and use of these terms, affecting the way NOS has been delivered. The second, Section 2.4, looks at the ways that NOS has been measured, a process that can help clarify NOS themes for teachers, and provide feedback for them concerning their delivery of NOS in the classroom. Finally, in

Section 2.5, the literature is examined to see if there is any empirical evidence for increased student engagement as a result of strategies used to teach NOS.

## **2.2 History of NOS and engagement**

### **2.2.1 Traditional science**

On rare occasions when delving into the origins of science and the scientific method, science teachers often start with astronomical observations made by ancient civilizations such as the Babylonians. The link is made between these observations and the inferences derived from them, such as calculating the length of the year. The importance of these empirical observations was described by Jarrard (2001), in a book written by a scientist for other scientists to better understand NOS. The use of empirical observations remains at the core of NOS descriptions today (Deng et al., 2011; Lederman, 2007; Osborne et al., 2003a) and continues to be the standard way that science teachers attempt to initially engage students. Just as the Babylonians began their investigations by making visual observations, it seems reasonable to ask students to find out about the world around them by using their senses.

By the beginning of the 20<sup>th</sup> century, science had helped transform societies, with the material benefits of the industrial revolution producing dramatic changes in all aspects of life. The science behind this was built on reasoned, logical thinking which Robinson (2011, p.97) described as still dominating the world today:

The achievements of the rationalist scientific world view have been incalculable. They include the extraordinary advances in medicine and pharmaceuticals and their impact on the length and quality of human life; sophisticated systems of communication and travel; and an unprecedented understanding of the physical universe.

The philosophy behind this world view in the early 1890s was empiricism, based on the concept that theories are tested using observations, often as the result of experiments. This process became known as the ‘scientific method’, which still forms the basis of much school science. An extension of empiricism, known as

logical positivism, proposed that theories must be verifiable through logical inference based on observable facts (Alters 1997). Laudan et al. (1986) described positivism, or logical empiricism, as “a well-developed and historically influential philosophical position” (p. 142). Ziman (2000) described this philosophy as ‘academic science’ and suggested that most scientists working in the Western world between 1850 and 1950 would have been following these procedures.

Thus, a stable and well supported view of NOS emerged and made its way into public consciousness through compulsory education systems that required the teaching of science. This positivist view of science was adopted as part of the challenge of coping with the massive increase in the number of students in the education systems of the early 1900s. For example, Levin (1991) reported that secondary school attendance in the United States increased from 200 000 to 1.5 million during the period 1890 to 1918. Lagemann (1989) described “a commitment to "hard," positivistic conceptions of educational science” (p. 210) on the part of Edward Thorndike, a prominent educational researcher in America in the early 20<sup>th</sup> century. Thorndike believed in control and testing, conceptualizing students as empty vessels to be filled with knowledge controlled by the teacher. It was not surprising then that science was presented as a body of facts to be learned. This enabled the maximum amount of knowledge to be delivered as efficiently as possible within the obvious budgetary and personnel constraints of the time.

The logical, empirical NOS became so accepted in the early 1900s that it extended into large parts of society. Frederick Winslow Taylor devised a theory of scientific management (Traver, 2006) to improve efficiency in industrial environments such as factories. This fitted well with Thorndike’s approach, so schools in America were set up to model factory systems with content knowledge as inputs and student test scores as outputs. The whole system was described as *instructionism* by Sawyer (2006) who described it as well suited to the industrialised economies at the start of the 20<sup>th</sup> century. This *instructionist* method of teaching has been identified as all too prevalent in schools even today, with Fensham (2008), stating that students still report, “learning science is simply a matter of being like a sponge, and soaking up this knowledge as it comes from the teacher or from the textbook” (p. 20).

This system has largely continued through to the present, with school structures regulated by timetables, bells, and standardised outputs in the form of tests and assignments. This is one of the reasons that today's teachers find it difficult to change their teaching style to encompass contemporary views of NOS, as not just science teaching, but the whole school structure is based on scientific principles from the early 20<sup>th</sup> century. Robinson (2011), described the formation of similar education systems in Europe and argued strongly that these factory systems were not suited to the 21<sup>st</sup> century. He called for a change to include elements more recognisable in modern NOS documents such as creativity and collaboration, which he claimed were essential in this rapidly changing technological age, and which would make school more enjoyable and relevant for students.

Others too have expressed doubts, from the earliest times, about both the whole education system and the way science was taught within this structure. According to Levin (1991), John Dewey, a leading educationalist of the early 20<sup>th</sup> century, supported a 'child centred' individualized approach to education, as opposed to the mass-produced factory system that came to dominate. Concerning science teaching and NOS, Dewey noted that scientists had developed a specialized language in order to accurately communicate precisely what they have been doing (Dewey, 1934), with this creating a communication barrier with the rest of the population. Paradoxically, while scientists had become removed from society, people in general had become immersed in the fruits of scientific endeavour, with every facet of their material existence changed by progress in science. Dewey (1934) described the key attributes of a scientific attitude as: "open-mindedness, intellectual integrity, observation, and interest in testing their opinions and beliefs" (p. 3), points that would sit well in a list defining NOS today.

Fostering intellectual capacities such as scientific attitudes in school students was far more important than accumulating a host of largely irrelevant facts according to Dewey (1934), a view that has a fresh relevance in the information age of the 21<sup>st</sup> century. As Claxton (2006) and Weinberger (2011) argued, now that the 'facts' are available to everyone through the internet, it is vital that we develop skills to think about, critique and use the information, a crucial part of NOS.

Although Dewey did not state explicitly that educating students using some of the principles described in today's NOS terms would be more engaging for them, it was strongly implied. He saw teaching specialized science content as appealing to only a small group who would go on and use the information in science-related careers. He believed that encouraging the use of scientific attitudes and methods of thinking would have much more relevance and practical use to the vast majority of students. This is an argument raised for inclusion of NOS in schools in many more recent reports (Bull, et al., 2010; McComas et al., 1998; Tytler, et al., 2008).

Another who argued that science teaching should be relevant to the everyday lives of students and enable them to solve problems was Davis (1935). He identified three distinct parts required in science courses: developing a scientific attitude; a scientific method of procedure; and building a fund of information. It is this last area that has dominated science teaching ever since, and contributed to the perception of science as content driven and boring by many students. In a recent study in Australia, Danaia, Fitzgerald, and McKinnon (2013) looked at senior science in high schools and found that copying notes and completing recipe-based practical work was still the dominant method of teaching. Moreover, over half the students surveyed saw no relevance of science to their future.

The importance of making science relevant was further emphasised by Davis (1935), who described how researchers at the University of Wisconsin arrived at a set of five attributes that would be held by a person with a scientific attitude, including being open to changing their minds on the basis of evidence, and drawing conclusions based on facts. Davis viewed this philosophy of science teaching as a way ensuring that students gained problem solving skills, useful to their future lives in society, and were not simply taught a body of scientific facts. He felt that the students would gain personal satisfaction from their science courses if teachers took this approach. The implication being that if students could see direct benefit to themselves from science courses, they would be more likely to be positively engaged.

By the middle of the 20<sup>th</sup> century Wilson (1954) assumed that all educationalists would agree that science should be included as part of the general education of all college students. However, he noted that the sheer volume of scientific knowledge

meant that it was more important to give college students an understanding of the way in which science works, its tactics and strategies, rather than the actual content in any given discipline of science. His survey of both college and high school students clearly showed they had a poor understanding of the place of science in society. He expressed no opinion related to whether the students themselves would be interested or engaged by NOS but argued that society needed informed citizens to be able to tackle the crucial scientific issues of the 20<sup>th</sup> century, a view echoed by proponents of NOS today (Gluckman, 2013a; Hipkins, 2012; Tytler et al., 2008).

The move away from regimented procedures and from content to creativity was given impetus by the science philosopher Karl Popper (1959). He contributed significantly to views on NOS by rejecting such tenets as the inductive logic of science, replacing this with a deductive method of testing. Popper contended that a hypothesis could be empirically tested, but to do so it must have been formulated in advance. That is, the views or theory held by the scientist directed the investigation, which ran counter to the empirical, positivist view that the theory could only be built from initial observations. Popper's ideas contributed to the view that science is a human endeavour, dependant on the experiences the scientist brings to the situation. Popper also provided arguments in favour of science as a process involving creativity and imagination, stating that scientific discoveries require "creative intuition" (Popper, 1959, p. 37). This is a notion that is supported by many scientists and educators today (Lederman, 2007; Tytler et al., 2008; Ziman, 2000), with creativity itself promoted as a way of engaging students (Robinson, 2011).

The current NOS view that scientific knowledge is firm but tentative was clearly supported by Popper's assertion that what defines a scientific question or theory is that it should be falsifiable rather than verifiable (Popper, 1959, p. 47). This view provides another reason why teaching NOS should be engaging to today's students as it presents science as a rebellious, questioning pursuit, encouraging the individual to put all assertions to the test. This seems to fit with the prevailing culture in many western societies where individual freedoms are highly valued, and accepted modes of behaviours constantly questioned. The traditional science lesson where transmission of science knowledge as a body of facts to be learned, conveys the message that science knowledge is fixed and rooted in the past. As Osborne et al.

(2003a) pointed out, a tentative view of science implies there is more to be discovered and should offer an exciting path into the future for today's students. A further argument for exposing students to the tentative NOS was provided by Cotham and Smith (1981), who attributed much of the cynicism shown by the public towards science to their false view that science knowledge is fixed or certain. If students understood the way science really worked, they might be fascinated when they hear about the rapidly changing claims made in fields such as astronomy and biochemistry, and so become more engaged in class.

### **2.2.2 Changes in thinking about science and NOS in the mid-20<sup>th</sup> century**

The philosopher Thomas Kuhn is acknowledged as being extremely influential in re-shaping many people's conceptions of the nature of science, with some (Abd-El-Khalick & Lederman, 2000; Wan, Wong, Wei, & Zhan, 2013) dividing 20<sup>th</sup> century philosophy of science into two periods separated by the publication of *The Structure of Scientific Revolutions* (Kuhn, 1962). Thus, an examination of Kuhn's work may enable us to see how it has affected thinking about NOS, and how the arguments he presented might help science teachers understand how and why teaching with a NOS approach could increase the engagement of students in their classes.

Starting his career in the pure sciences, Kuhn completed a doctorate in physics at Harvard University, but changed his focus to the history and philosophy of science when the course he was taking touched on the history of science (Kuhn, 1962, p.vii):

To my complete surprise, that exposure to out-of-date scientific theory and practice radically undermined some of my basic conceptions about the nature of science and the reasons for its special success.

This revelation came after Kuhn had completed many years of formal science training which made no mention of the rich history and traditions of science, let alone explicit teaching about NOS. Unfortunately, this seems to have continued, with few scientists or science teachers taking courses on NOS or philosophy of science as part of their training (Gallagher, 1991), although there have been attempts to rectify this (Abd-El-Khalick, 2005).

Many of the concepts Kuhn examined and clearly explained can be seen in modern papers and curricula concerning NOS. For example, he argued that scientists bring their own views and experiences to bear on problems, experiments or data, and thus can produce differing conclusions or theories based on the same evidence (Kuhn, 1962, p. 76). Kuhn also described how difficult it was for early scientists to agree on any particular theory when initially drawing together observations, without a preconceived paradigm in which to place them. He argued that this is often still the case when scientists seek to interpret new evidence, thus implicitly supporting the current 'sophisticated' NOS view (Deng et al., 2011), that scientists will always bring a degree of subjectivity to their work, based on their prior experiences.

A valid approach used by many science historians was also identified by Kuhn, who suggested that the work of figures such as Galileo should be viewed from the perspective of his contemporaries in the cultural and social context of the time. This underpins many modern NOS statements that refer to science as being influenced by, and influencing, the society and culture in which it is embedded (Lederman, Adb-El-Khalick, Bell, & Scharz, 2002; McComas et al., 1998). Fensham (2008) too, highlighted the importance of including alternative views towards science and nature from different cultures. He argued this would help students from indigenous peoples engage with science, and he recommended that governments include these NOS ideas in science curricula.

Important as social interactions are between science and society, it is the social interactions within science itself that are vital to its success, according to Kuhn (1962, p. 166). A great strength of science is the role of communities of scientists in checking the standard and validity of the work of its members, the process of peer review. Because of the expertise built up within a particular science speciality, and the commitment to the currently accepted explanations, or paradigm, scientists are able to finely critique each other's work. Critical testing and peer review is recognised as a crucial part of NOS (Osborne et al., 2003a; Ziman, 2000) and can have a part to play in engaging students in school science. If teachers can make it clear to students that this a key part of science, and create an environment where questioning and discussion of ideas is supported and respected, then students will feel secure and gain the confidence to tackle difficult concepts, a key part of both

emotional and cognitive engagement. Crawford (2005) demonstrated this with middle school students who responded positively when questioned and challenged about their investigations, modelling scientific peer review in the classroom.

Perhaps Kuhn's most famous contribution to thinking about science concerned the revolutions of scientific thought, since popularised through the term 'paradigm shifts'. He argued that 'normal science' is governed by sets of assumptions regarding the way the world works, described as a paradigm. Scientists work within these paradigms until anomalies are thrown up which cannot be explained by the current thinking (Kuhn, 1962, p. 75). A revolution in thought is then needed in order to create another set of assumptions or theories which do account for all existing evidence, a new paradigm. The paradigm shift as a way of explaining progress in science has become well accepted and provides good grounds for the NOS concept most commonly expressed as science being both firm and tentative.

This view of NOS presents many opportunities for engagement of students in school science, and foreshadows much of the literature around NOS. For example, making students aware of the phlogiston theory of combustion, and how this was a successful paradigm at the time, has been shown to be a successful way of engaging students and changing their views about NOS (Allchin, 1997). Osborne et al. (2003a) too, suggested that using the history of science to illustrate past paradigms which seem ludicrous today, could provide the hook that engages students.

Realising that scientists have to challenge traditional thinking and authority in order to change ideas, should be engaging to students. Both teenagers and scientists come up against rules, regulations and laws of society and science, and constantly push the boundaries. If students can empathise with scientists facing similar problems to themselves, perhaps they can begin to see themselves as scientists, an aspect considered an important influence on students choosing to continue with science subjects at school (DeWitt, Archer, & Osborne, 2013; Mead & Métraux, 1957). In Kuhn's view, scientists are people who develop their own views based on observation and evidence, which are open to challenge, argument and debate. Kuhn used the term argumentation (1962, p. 94) to describe how scientists must persuade others to accept a new paradigm, and this process of argumentation has since been

recognised as a worthwhile strategy to teach NOS and engage students in science (Dawson & Venville, 2010; Deng et al., 2011).

Another characteristic of NOS strongly supported by Kuhn's idea of paradigm shifts is the need for scientists to be creative and imaginative. These attributes are certainly required to formulate a new explanation, theory or paradigm. A criticism of much science teaching in schools is that it does not foster, or even mention creativity, rather presenting science as a body of facts to memorise, a process seen as boring by many students (Mead & Métraux, 1957; Osborne et al., 2003b). If, by contrast, students come to realise that creativity is at the heart of science and they are given opportunities to be creative themselves, their engagement is likely to improve. Creativity can be introduced by asking students to design their own experiments or choose their own problems to investigate, which also gives students more ownership of their learning, another factor reported to increase engagement (Ebenezer & Zoller, 1993; Freire, Faria, Galvao, & Reis, 2013; Newman, 1992).

Creating a new paradigm is extremely difficult, which is why Kuhn described it as requiring a revolution in thought. He made it clear how difficult it was for scientists and the scientific community to accept new ideas and interpretations of previously well explained events, describing the conditions needed as a 'crisis state' (Kuhn 1962, p. 85). A similar idea, called cognitive conflict, has been used by many researchers to describe successful strategies to produce conceptual change in students' thinking (Driver, 1989; Duit & Treagust, 1998). People bring their preconceived ideas and explanations to any new situation and they are often very successful in accounting for observed phenomena, even if incorrect according to current scientific thinking. Thus, conceptual changes, like paradigm shifts, are very difficult for many. Solomon, Duveen, and Scot (1992) observed the cognitive conflict felt by students when taught through a history of science perspective. They concluded that it did help students move to a more mature view concerning theory creation and use, as well as improving their understanding of the scientific concepts. If these views of NOS were presented to students as they grapple with the many observations, facts and theories they are expected to assimilate, then they may well feel more emotional and cognitive engagement with science. They should be encouraged to see that they are not alone if they have feelings of confusion or

frustration when they ‘don’t get it’, as this a normal part of science. Conversely “the excitement and thrill” (Osborne et al., 2003a, p. 694) that comes when things do fall into place, is a strong motivator for both science students and professional scientists.

The insights Kuhn made regarding the difficulties in the formation of new scientific paradigms helps explain why many teachers and students have difficulty clearly defining and understanding NOS. They have been operating in the traditional paradigm that views science as a body of knowledge that needs to be learned by students. Many science textbooks too, use this traditional approach, presenting a disengaging view of science at odds with the contemporary view of NOS. Students are not presented with a realistic impression of NOS in text books, but with a body of knowledge presumed correct. Gallagher (1991) supported this view, noting that most secondary school science texts contain cursory reference to NOS with the rest devoted to factual knowledge. Most references to historical figures that are placed in science text books (Kuhn, 1962, p. 138) contribute to the view that knowledge has gradually accumulated and this is of course seen in the light of the current paradigm being explained. There is usually no sense of the turmoil of opposing views at the time, and so of the creative leap needed to launch the new paradigm.

Another area of NOS addressed by Kuhn, and that appears commonly in science education literature, concerns the understanding of laws and theories, and the place of each in science. Many science teachers and students have been shown to have limited understanding (Lederman, 2007; McComas, 2004) of the relationship between laws and theories, with many seeing laws as more important. Kuhn provided a counter to this view when he argued that an initial ‘qualitative’ paradigm or theory is necessary before a quantitative law can be established by experiment and measurement (Kuhn, 1962, p. 28). Students may become cognitively engaged when relationships such as these are explicitly taught. If, rather than simply being presented with Ohm’s Law as a ‘fact’, they view it as a consequence of the theory of electricity, their broader understanding of the topic will be enhanced and their feeling of competence will increase, a factor seen as significant for student engagement (Newman, 1992; Skinner & Pitzer, 2012).

One criticism of school science has been the use of recipe-type experiments by many science teachers, with the intention of delivering practical, engaging lessons. Too often these become merely processes to follow, of little interest to the students, producing few advances in understanding (Abrahams & Reiss, 2012; Ebenezer & Zoller, 1993). Giving teachers and students a rationale for some of these familiar experiments which are known to work successfully in the school setting, could well increase the engagement of both parties. Kuhn, (1962, p. 37) provided a way of justifying this when he described a key purpose for science as validating existing paradigms. Students could be told that they are doing real science even when carrying out simple experiments. They are testing current hypotheses and theories for themselves, the same process as done by practising scientists. Making tasks in school more authentic is regarded by Newman (1992) as an important component in increasing the engagement of students, so making an explicit link between NOS and school science practicals could help in this regard.

This view of science as hypothesis testing was central to Popper's (1959) philosophy of science, and its power and appeal noted by several participants in the Delphi Study carried out by Osborne et al. (2003a). Here hypothesis formation and testing was linked closely to creativity in science and was seen as a skill relevant to the lives of students beyond science. It helps them to think critically about almost any topic. The standard science experiments could be presented to school students in this light, that is, as part of a puzzle that seeks to provide evidence for or against a particular theory. Puzzle-solving and meaning-making are emotionally and cognitively engaging (Willingham, 2009) and provide much of the motivation for professional scientists. School students are likely to be engaged through these same processes, especially if they are encouraged to view the skills as transferable to problems in their own lives. Staver (2007) and Tytler et al. (2008) both supported this view, recognising that problem solving is required to gain a deep understanding of science, and is one of the key activities carried out by effective science teachers.

Finally, Kuhn argued that much of the success of science in making progress (Kuhn, 1962, p. 165) and transforming society over the last two hundred years has been due to the stability of each paradigm and the commitment of the scientists who work within its boundaries to the accepted theories. This is the 'durable' part of the

‘science is tentative but durable’ tenet, seen in many NOS curriculum statements and research papers (Deng et al., 2011; Lederman, 2007; Ministry of Education, 2007a). Kuhn’s view was that because a community of scientists in a particular field all agree on the basic paradigm, they can focus on applying that knowledge to problems that lead to rapid advances. The education of students into the advanced sciences is based on this premise, with the efficient absorption of knowledge within that paradigm being the goal, right through to third year university level. As noted earlier, textbooks are written to support the current paradigm in order to move students quickly to the position where they are able to contribute to the current research effort. This may be an effective way to educate future scientists but as science educators have pointed out over the years (Cooley & Klopfer, 1963; Fensham, 1985; Tytler et al., 2008), there is also a need to equip the majority of students who will not pursue a science career for their futures as citizens in a society dependent on science and technology. Pointing out to both these groups, the future scientists and citizens, the power of learning within the current paradigms and the excitement of challenging these, could well be a way of increasing their engagement in science.

### **2.2.3 Turmoil in science education and philosophy of science in the late 20<sup>th</sup> century**

A common, recurring theme in the science education community is that teachers do not have a good grasp of NOS and therefore will not be able to impart a genuine appreciation of NOS to their students (Lederman and Lederman, 2014). One of the reasons for this could be due to the confusion and conflict at times amongst the science education research community, including scientists and philosophers of science, as suggested by Osborne et al. (2003a). Their arguments about constructivism, epistemology of science and NOS eventually filtered down to practicing teachers, but did little to convince them to adopt new teaching approaches. Another related problem identified by Eisner (1984) was the difficulty of transferring educational research into teacher practice. Hattie (2009) too noted that despite the multitude of research papers showing what works in the classroom, there had been little real change in the way teachers operated. Kantrowitz (2014) reported that many in education still saw this as a major problem, despite attempts such as the *What*

*Works Clearinghouse* (n.d.) to bridge the gap between educational research and teaching practice.

My own experience of this turmoil was in the 1990s when the debate on constructivism reached the community of secondary school science teachers in New Zealand. This was the only time I can remember any specific educational theory stirring those at the ‘chalk face’ in over twenty-five years as a teacher. Meetings were held by local science associations and at national science teachers’ conferences as the advantages (Bell, Kirkwood, & Pearson, 1990) and disadvantages (Matthews, 1995) of a constructivist approach were vigorously argued. My overall, if somewhat hazy, recollections of this time are that there was some merit in helping to construct students’ views of scientific principles but that expecting them to do this themselves from experiments and observations was not really credible. Hodson (1996) specifically criticised the dominant constructivist view in New Zealand of the 1990s simplified to, ‘we are all scientists’, describing this as absurd, and one which failed to give a realistic view of NOS.

Despite these difficulties, there was much useful research concerning NOS following the upheaval caused by Thomas Kuhn and others. There was an increasing realisation that teachers, students and the general public did not have a good understanding of the way that science worked, and that a clear description of NOS was needed. Cooley and Klopfer (1963) were one pair of researchers who saw the need for improving students’ understanding of NOS, or what they described as the intangibles of science. They developed both an intervention based on the history of science and a Test for Understanding Science (TOUS) to measure the impact of their teaching strategy. This instrument consisted of three sections: understanding about the scientific enterprise; about scientists; and about the methods and aims of science. Through the process of consulting a variety of science educators, scientists and philosophers of science, they produced a list of eighteen themes under the three broad headings, including, the ‘human element of science’ and ‘accumulation and falsification’. The findings from several surveys indicated that the knowledge of the general public about science was woefully inadequate. Although Cooley and Klopfer felt that this understanding was crucial for both the individual student and society in general, they

made no attempt to find out if the students themselves were more interested or engaged by explicitly learning of this type of knowledge.

Another researcher concerned about the low levels of NOS knowledge being reported was Kimble (1967). He investigated the level of NOS understanding in science teachers, scientists and philosophy majors and the differences between them. His aim was to find out where resources should be targeted in order to improve NOS understanding in schools. To do this he created his own instrument for measuring NOS knowledge, the Nature of Science Scale (NOSS), by first formulating his own theoretical model of NOS. This was drawn from the science education and philosophy of science literature and consisted of eight key statements, including aspects referring to science as requiring curiosity, tentativeness, openness, and proceeding through a wide variety of methods.

The level of NOS understanding found by Kimble (1967) was similar, but lower than expected in both science teachers and working scientists, and he found that length of teaching service made no difference to NOS knowledge. These types of findings continue to be reported forty years later with a recent Spanish study (Vázquez-Alonso, García-Carmona, Manasserro-Mas, & Bennàssar-Roig, 2013) finding that experienced science teachers held naïve views in many NOS areas. Interestingly, Kimble found higher levels of NOS knowledge amongst philosophy majors, and so suggested that requiring both science teachers and undergraduates to take philosophy of science courses might be an effective way of raising NOS knowledge more widely, a view echoed by Carey and Stauss (1970).

The philosopher Feyerabend (1975) added to the turmoil of the times, through his assertions that there was no one scientific method, and no absolute scientific facts. He criticised science as presented in schools as boring and dehumanising. He described science education as “making the history of science duller, simpler, more uniform, more ‘objective’”, and added that “imagination is restrained” (p 11) in most school science classes. If science was seen as a human, personal process, with argument and debate, dependant on creativity, then surely it would be more engaging for students? Feyerabend described this view of science as “complex, chaotic, full of mistakes, and entertaining” (Feyerabend, 1975, p. 11). These views do not however,

seem to have reached the science classroom, where reports from the succeeding years indicate little change to the dull delivery of content.

In a survey of staff and students at the University of Adelaide, Rowell and Cawthron (1982) attempted to find out if views on NOS had been influenced by the debate over the ideas presented by Popper (1959), Kuhn (1962) and Feyerabend (1975), or if the traditional logical positivist view still prevailed. Rowell and Cawthron concluded that the prevailing view was of an image of science as 'objective', and argued that if students were encouraged to think of science as a human endeavour it would have more meaning for them. If they learned about science in its social and cultural context, gaining an appreciation of how and why science works, they would be better able to examine their own views and make critical decisions in their own lives. This view has recently been embedded into the Australian curriculum (ACARA, 2015). It includes 'Science as a Human Endeavour' as one of three strands, and requires teachers to make explicit the place of science in their students' everyday lives, in order to generate interest or engagement with science.

Another educational researcher Miller (1983), found that even sixteen years after Kimble's (1967) work, the level of scientific literacy was still extremely low in America, resulting in poor public understanding of the big issues of the day. According to his survey data, only seven per cent of the respondents were scientifically literate. Miller pointed out that if school students gained a better understanding of NOS, they would be able to make informed decisions about important scientific issues themselves. Having the knowledge and confidence to make your own decisions are key parts of becoming a competent citizen. Newman, Wehlage, and Lamborn (1992) described this need for competence "as one of the most powerful bases for human action and motivation" (p. 19), and hence a driving force for student engagement with school.

Miller (1983) went on to propose that primary and secondary schools would be the most effective places to implement changes to improve science literacy. He made no actual claim that students would become more engaged with science through improved science literacy, although it is a reasonable assumption that if the wider populous is engaged in debate over issues such as genetic engineering or nuclear

power, then so will the student population. Seeing the relevance of school science to their own lives is regarded as important in order to engage students (Tytler et al., 2008). However, personal relevance is often identified as missing from students' experiences in school science (Barmby, Kind, & Jones, 2008; Osborne et al., 2003b).

These calls from Miller (1983) and others to change the way science was taught in schools was not helped by the continuing controversy concerning NOS between science educators, philosophers and scientists. The situation in the wider science community was certainly recognised to be in a state of confusion by Laudan et al. (1986). They acknowledged that where there was once general agreement concerning the philosophical underpinnings of science, that of logical empiricism or positivism, this had now been rejected. The work of Kuhn (1962) and Feyerabend (1975) amongst others, revealed that the accepted positivist view of NOS was not how science was currently carried out, or indeed may never have been. Laudan et al. (1986) went on to state: "The fact of the matter is that we have no well-confirmed general picture of how science works, no theory of science worthy of general assent." (p 142).

These concerns about a lack of consensus regarding NOS continued to be expressed right through this period up to the end of the 20<sup>th</sup> century (Abd-El-Khalick & Lederman, 2000). So, it is hardly surprising that teachers, students and even practising scientists had what many science educationalists described as a poor or naïve understanding of NOS. If the experts in the field could not agree on what constituted NOS, how could teachers be expected to deliver NOS in their classes?

Despite these problems, Hodson (1988) reported that many science courses around the world had changed from a focus on science as a body of knowledge to science as a more human activity with a process-oriented approach. These changes had also been noted much earlier by Carey and Stauss (1970) who commented on the difficulties facing teachers in keeping up with shifting content, methodology and philosophies in science. The aim of curriculum reform was to encourage more students to continue with science, to gain an appreciation of NOS and to increase their enjoyment of science. However, Hodson cited numerous research efforts supporting his view that these aims had largely not been achieved, and he went on to

argue that a significant reason for this failure was poor application of the philosophy of science by both teachers and curriculum designers. This point was supported by Duschl (1988) who called for the involvement of the wider community of historians and philosophers of science in order to accurately represent NOS in the American curriculum. He saw this as vital to counteract the disenchantment of students when science was presented to them as a set of facts.

Another research team, Carey, Evans, Honda, Jay, and Unger (1989) acknowledged that process skills, including the scientific method, were being taught in American schools, but in a mechanical way with no attempt to explain why these skills are so crucial in constructing scientific knowledge. They argued that these skills should provide the basis for students to challenge their own ideas, implying that this challenge would be appealing to students. Matthews (1989) strongly supported these views while criticising science curricula in Australia, America and the United Kingdom based on science as inquiry with an empirical, inductivist basis. He argued that not only did this inadequately represent science as currently practiced or described by the more modern philosophers of science such as Kuhn, but that if these contemporary views were taught, students would be more engaged. Matthews, echoing the work of Kuhn (1962), reasoned that if students were shown some of the problems faced by scientists throughout history as they attempted to explain observations and experiments, this would help them with their own conceptual change challenges.

Initiatives concerning NOS in the British science curriculum were described by Solomon (1991), who also advocated for the inclusion of a history of science component on several grounds, some of which relate to the motivation of students. She suggested that both viewing past scientists as ‘heroes’ and including stories about real people in science, could create an emotional connection for students. This view was supported by Fensham (2008) who reported “positive affective and cognitive responses” (p. 21) from students taught through the use of stories involving real characters from the history of science. Solomon, however, acknowledged that introducing ‘little snippets’ of history into science lessons was not effective in producing real understanding about the tentativeness of science, with students more often simply viewing past scientists as ignorant and wrong. This view was supported

by Meyling (1997), who found that it was very hard to move students from those naïve views of past scientists despite exposure to the philosophies of Popper or Kuhn.

Concerns were also raised about the difficulties facing science teachers in delivering NOS by Solomon (1991), who suggested that teaching the processes of science by carrying out experiments or even open-ended investigations might not give students any real understanding of NOS. Allchin (1997) and Meyling (1997) showed that key NOS concepts could be influenced by well-designed units of work, but that these required a teacher with exceptional skills and knowledge who was prepared to put in a great deal of extra work. Some of the reasons for teachers struggling to deliver NOS lessons were clearly described by Gallagher (1991), the main one being their lack of formal education concerning the history, philosophy or sociology of science. Without this training *about* science, teachers had great difficulty in planning lessons that enabled students to think of science other than as a body of knowledge.

In a review of the literature concerning NOS, Lederman (1992) found research papers indicating that some teaching curricula and strategies did improve NOS understanding in students, while other studies indicated no change. This uncertainty would not have helped convince teachers to abandon their traditional and familiar teaching styles in favour of including NOS as part of regular practice. Lederman also noted a growing appreciation of the complexities and constraints faced by teachers in trying to introduce NOS, such as the pressure from the regular curriculum, and the burdens of administration and assessment.

On the positive side, Lederman identified findings from research which pointed out aspects of teacher practice which seemed to be effective in the classroom. Teachers who maintained supportive learning environments where students felt able to voice opinions, and who used higher level questioning along with problem solving and inquiry approaches to practical work, were more likely to produce improved understanding of NOS. These same characteristics appeared in more recent research linking them to students' positive attitudes towards science (Osborne et al., 2003b; Martin-Dunlop, 2013). Thus, the factors that contribute to better NOS teaching and

learning seem to be those that improve student attitudes as well, and positive attitudes are a good indicator of engagement (Finn & Zimmer, 2012).

Links between NOS teaching and engagement were indicated by the research of Meyling (1997). His was an extensive study which specifically attempted to alter the epistemological views of students in senior high school physics classes in Germany. Over a two-year programme integrating the philosophy of science into regular physics classes, Meyling provided structures enabling students to reflect on their own views of science and compare them to those of prominent philosophers and practitioners of science. He concluded that shifts were able to be made from a naïve realism to a more sceptical and sophisticated view of NOS, but that this was not an easy process for either teacher or student. However, students seemed to enjoy and appreciate the opportunity to explore the ideas underpinning science with eighty-six per cent stating they approved of these epistemological discussions. This research supported the notion that integrating NOS concepts into regular science does engage students, although few current teachers would have the skills and knowledge needed to cover the material to the depth described by Meyling.

Another problem for those wanting NOS to be delivered in schools was uncovered by Tobin and McRobbie (1997). In a study of a high school chemistry teacher and his class in Australia, they found that although the teacher had an excellent grasp of NOS and his students agreed with his philosophy of science, the actual teaching in class was mostly the simple transmission of knowledge required to pass the tests. There was little attempt to promote deeper understanding of science and its workings, or to question the assumptions and observations made during demonstrations. As Tobin and McRobbie noted, both teacher and students were comfortable with this approach as it satisfied their mutual goal of preparation for university courses, and so students were motivated enough to accept the passive nature of the lessons. However, most students in junior high school have not yet decided on a future course of study, and many argue that teaching with a NOS approach will improve the engagement of these students (Bolstad & Hipkins, 2008; Bull et al., 2010). The problem raised by Tobin and McRobbie (1997) then becomes how to convince teachers to use NOS strategies as they may not naturally teach in this manner even though philosophically they may agree with the principle.

Yet another problem concerning the teaching of NOS was raised by Alters (1997), a philosopher of science. He expressed doubts about the science education community's findings concerning NOS, both the list of tenets defining it and the results of attempts to measure NOS understanding. He reasoned that if NOS knowledge was universally acclaimed as beneficial to students and society, then it was important to have agreement over exactly what it was, and consequently how it should be taught. To try and produce a more valid view of NOS, he conducted a survey of over 200 philosophers of science and discovered there were many different views and serious disagreements with those expressed by science educators.

One partial solution to this problem came from Ziman (2000), a physicist with a desire to explain how science really works and to dispel some of the doubts and uncertainties about NOS raised by sociologists and philosophers of science. Ziman stressed the place of science as a cultural entity within society, with scientists having a shared belief that the world around them can be explained. However, he described what scientists actually did in more traditional terms, such as making observations and carrying out experiments to test hypotheses. He also made a strong connection between science producing knowledge and the communication of that knowledge. These aspects of NOS are helpful to teachers as they regularly carry out experiments and require their students to communicate their understanding of science, especially in formal assessments. Recognising that doing science requires communication of science provides justification for some aspects of NOS, and hence may increase teachers' willingness to deliver NOS. The NOS strand of the New Zealand curriculum (Ministry of Education, 2007a) recognised the importance of this aspect by including communicating in science as one of its four core themes, as discussed in Section 3.3.2.

The turmoil of the previous decade in the science community was described by Osborne et al. (2003a) as the 'science wars', waged between science educators, philosophers and scientists, vigorously debating NOS. This view was previously noted by Jenkins (1996) who included sociologists of science in the debate, suggesting that they provided an even more complex picture of NOS. Hodson (1996) too, described the successive science education approaches over the last few decades, such as discovery learning, inquiry as a process, and constructivism, as all having

strong advocates but significant flaws. However, Abd-El-Khalick, Bell and Lederman (1998), dismissed much of this controversy as irrelevant to high school teachers and far too abstract to bring into classroom discussions about NOS.

None of this higher-level debate, of course, helped science teachers deliver NOS ideas in the classroom, but possibly contributed to teachers holding onto more traditional views with which they were familiar. However, as previously noted, there were still some research projects being conducted (Alchin, 1997; Carey et al., 1989; Klopfer & Cooley, 1963; Meyling, 1997), which did demonstrate how NOS could be delivered in schools, and mentioned the increased engagement of students that resulted, alongside improved understanding of NOS.

#### **2.2.4 Towards consensus regarding NOS – heading into the 21<sup>st</sup> century**

Leading up to the year 2000 and beyond, the prevailing mood in science education moved towards a working consensus about what should be defined as NOS, and agreement on the benefits of improving NOS knowledge in teachers, students and the wider populous. McComas et al. (1998) for example, presented a summary of NOS objectives drawn from international science curriculum documents and commented that these were entirely acceptable for use in high schools, even if there was still argument about them amongst philosophers of science. He pointed out that in the spirit of science inquiry itself, science teachers should be encouraged to present different interpretations of NOS, even if they were not comfortable with the particular tenets mandated in curriculum documents.

Some more definitive conclusions came out of a review of efforts to improve teachers' NOS knowledge by Abd-El-Khalick and Lederman (2000). For teachers to be able to deliver NOS in science classrooms, it was argued that not only did they need very good NOS understanding themselves, but also good pedagogical content knowledge (PCK) for NOS; that is the activities, experiments and historical examples that serve to convey NOS knowledge explicitly and effectively to students. Bartholomew, Osborne and Ratcliffe (2004) strongly supported this need for PCK concerning NOS, noting that it allowed teachers to create situations where they could guide and facilitate learning, rather than simply dispense information. In analysing

numerous interventions designed to improve NOS understanding of teachers, Abd-El-Khalick and Lederman (2000) found that significant gains were made only when explicit strategies were used, such as higher level questioning and structured reflection.

Adding to the growing consensus about NOS for teaching in schools, Osborne et al. (2003a) reported on a major Delphi Study which they carried out to provide clear guidance concerning what should be taught in schools regarding NOS. While acknowledging the problems raised by philosophers of science such as Alter, Laudan and others, they argued that it must be possible to develop a set of simplified criteria defining NOS suitable for use in schools. This would in all probability not be met with unanimous agreement by philosophers of science but would give certainty and direction for science teachers. Eventually a list of nine key themes considered the most important to include in school science were produced, such as the need for creativity and the importance of cooperation and collaboration. Although engagement of students was not mentioned specifically, several participants made comments indicating that learning about NOS would be of more interest to students due to its increased relevance and as an “antidote to rote learning” (Osborne et al., 2003a, p. 707). This strongly implied that teaching NOS would improve the engagement of students.

In a major review of NOS literature, Lederman (2007) supported the idea of a working consensus of NOS themes to be used in schools. He rejected the need for complete agreement by philosophers of science and others as impractical and irrelevant for teachers in science classrooms and produced a list of six key aspects that should be taught in schools, including the tentative NOS and the difference between theories and laws. Lederman also indicated that a consensus existed concerning research findings about teachers and NOS, with two key points noted. First, most science teachers possessed limited NOS knowledge, and their length of service or academic backgrounds did not significantly relate to their NOS understanding. Second, the most effective strategies for improving NOS knowledge in teachers involved explicit instruction about NOS, or historical approaches, with both requiring considerable personal reflection.

Significant support for the explicit teaching of NOS was provided by Bell, Matkins and Gansneder (2011), who found that NOS instruction was most effective when it was “explicit in lesson objectives, purposefully taught and specifically evaluated” (p. 430). Other effective ways of teaching NOS identified by Lederman (2007) included use of inquiry and open-ended questioning by teachers, setting problem solving activities for students, and creating learning environments where students felt comfortable about voicing opinions. All these strategies have also been found to also increase the engagement of students (Cornelius-White, 2007; Pintrich, Marx, & Boyle, 1993).

While these conclusions from Lederman (2007) and Osborne et al. (2003a) provided more certainty for science educators about what to teach about NOS and successful strategies for how to teach NOS in schools, they still did not address the question of why teachers would chose to teach and value NOS. There were some hints, for example in Dhingra’s (2003) study of the use of television programmes in science classes. Dhingra found that students were more engaged when exploring tentativeness in science and encouraged to ask questions of their own. However, in general, more obstacles to teaching NOS have been identified than solutions, including: the value placed on memorising content for high-stakes assessment; the constraints of school systems and structures; and the difficulty of producing or accessing suitable teaching resources (Bartholomew et al., 2004; Harland & Kinder, 1997; Hipkins, 2012).

Recognition of the difficulties faced by science teachers was picked up by Staver (2007) as part of a United Nations Educational, Scientific and Cultural Organisation (UNESCO) series summarising best practice teaching. He stated that the key determinant of an effective teacher was that they have a clear purpose. This is a problem for many teachers regarding NOS, as they make preparation for examinations their main focus rather than instilling a deep understanding and appreciation of science. Staver also noted that to be effective, teachers must know their students well, and help them to construct their own knowledge through the use of activities perfectly judged to extend them, but which lie within their capabilities and are relevant to their lives.

A major Australian review with the aim of improving engagement with Science, Technology, Engineering and Mathematics (STEM) in schools largely agreed with this advice. Tytler et al. (2008) identified some key areas of school science that required changing in order to more accurately represent the current NOS as practiced by scientists. These changes were also seen to be more relevant and engaging for students, compared to traditional content demands requiring facts to be memorised. However, Tytler et al. (2008) appreciated that this required teachers to possess excellent NOS knowledge and have the flexibility of approach to accommodate the differing learning needs of their students.

With a common view established concerning what to include in courses requiring NOS, the attention of many turned to how to teach NOS, given the complex demands on teachers. Some of these strategies are described in Section 2.2.4, but an important point arising from these relates to the use of the NOS tenets themselves. Clough and Olson (2008) expressed concern that while useful for identifying key aspects of NOS, teachers might simply teach these tenets as a set of NOS facts to be learned, rather than weaving them into appropriate contexts. Allchin (2011) also criticised the emphasis placed on lists of NOS concepts and proposed that teachers should combine teaching and assessment of NOS using authentic, context-rich case studies. However, he did acknowledge that a list of NOS concepts should be used to check that all aspects had been covered over a whole science course. McComas (2008) used a list of NOS tenets to produce a selection of historical vignettes from popular books on the history and philosophy of science. He reaffirmed that teachers using these examples need to make the NOS concepts explicit to students, and claimed that students would be more engaged when presented with stories of genuine scientists wrestling with NOS issues from the past.

As one of the key personnel involved in the writing of the New Zealand science curricula (Ministry of Education, 1993, 2007a), Hipkins (2012) clearly described the reasons for including NOS and the challenges that teachers faced when implementing NOS in the classroom. One of the prime reasons given for including NOS was to increase the engagement of students in science by making science more relevant and useful to them in their lives outside of school. However, Hipkins acknowledged that there was little evidence that significant changes had been made in New Zealand

science classrooms as a result of the curriculum initiatives. She argued that two key factors were required to produce real change. First, teachers needed to accept that the purpose of science education in the 21<sup>st</sup> century required NOS, and that teachers must come to value and embrace this new approach. Second, teachers must be provided with significant support and training so that they could see how to implement NOS in their classrooms.

These two factors were labelled by Harland and Kinder (1997) as *value congruence* and *knowledge and skills*, rating them the most important out of the nine key outcomes required to change teacher practice. Abd-El-Khalick et al. (1998) showed that even with specific training to promote both these factors, pre-service teachers failed to plan and deliver explicit NOS activities in their classrooms. However, one method that did show improvements in this regard was demonstrated by Abd-El-Khalick (2005). A course on the history and philosophy of science was created to specifically enable teachers to transfer sophisticated NOS knowledge into classroom practice. It was observed that after the course, some teachers began to incorporate NOS into their own thinking and planning, with the aim of including these concepts into regular lessons.

However, even with the emergence of a substantial number of teaching strategies for NOS (Aydın, Demirdöğen, Muslu, & Hanuscin, 2013; Deng et al., 2011) and general support for NOS, the research continued to show that it was not an easy task for teachers to include NOS as part of regular practice. Bartos and Lederman (2014) provided an in-depth study of four physics teachers with good NOS knowledge and personal belief in its value. They investigated whether the teachers' own views of NOS matched the activities and procedures they used in the classroom. Although the teachers did often make explicit to their students many NOS concepts, these events were not planned or assessed in the same way as regular content, despite the teachers professed commitment to NOS and the knowledge that they were part of an intensive research project.

This highlighted the long recognised increased value of content compared to NOS in the minds of teachers, and the lack of PCK for NOS, which makes it hard for teachers to select and use effective activities. Expert teachers generally have

excellent knowledge of their subject matter in, for example, physics. Teachers of NOS also need excellent subject knowledge, in order to integrate this with the subject matter and the teaching context. With that knowledge comes the confidence to bring in NOS ideas at just the right time in a lesson and ask just the right questions. Bartos and Lederman (2014) specifically noted that one teacher consistently gained high engagement of students through his questioning techniques, “done almost effortlessly” (p. 17) both in whole class and small group situations, showing that when NOS knowledge and PCK combine, increased engagement can follow.

Unfortunately, as already mentioned, these aspects are not easy to combine. The difficulties in achieving this were well illustrated by Spiller and Hipkins (2013) in a project to support two experienced science teachers in New Zealand. The teachers and researchers worked together over a period of months to implement strategies delivering NOS in the spirit of the science curriculum. Through the use of more open-ended, student-centred tasks, the teachers noticed the engagement and rate of task completion of their students improved. However, this was still not enough to instil lasting changes in teacher practice. The prime focus for the teachers remained delivering content and preparing students for major assessments. Although temporary changes were made, without the continuing support of the researchers, they soon reverted to more traditional methods of teaching. This even with the improvements in student engagement noted.

More positive outcomes were reported by Lederman and Lederman (2012) from two large scale professional development programmes in the Chicago area. Project ICAN (Inquiry, Context and Nature of Science) and the High School Transformation Project (HSTP) both involved some hundreds of teachers and thousands of students over a period of three or more years. Teacher and student understanding of NOS and SI were found to improve, along with students’ scores in assessments on regular content knowledge. The changes were attributed to sustained, regular support and instruction by the professional development team and the use of coaches placed in schools. Teachers had first to build their own knowledge of NOS and SI through explicit instruction and reflective practices, before they developed the confidence and PCK needed to include these regularly in appropriate classroom contexts. These

projects demonstrated the extent and scale of the time, resources and expertise required to produce significant change in school districts.

Finally, two major reviews of NOS (Deng et al., 2011; Lederman & Lederman, 2014) reported similar findings concerning effective strategies for improving NOS understanding in teachers and students. These came from an increasingly diverse research community as countries all over the world have come to include NOS in their science curricula. Both reviews agreed that effective NOS instruction requires questioning and reflective techniques that make the concepts explicit for the learners, whatever the teaching strategies used. These findings were strongly supported by Hattie (2009), who carried out an extensive meta-analysis of the literature to discover the factors that made the most significant improvements to students' learning. One of the key factors Hattie reported was for teachers to make the required learning visible to students, that is, to make the learning intentions explicit. Only when both students and teacher knew exactly what was required could other strategies such as feedback and reflective practices be used effectively.

The question of why teachers continue to value traditional content in science over NOS was again raised by Lederman and Lederman (2014), but there was little mention of any research related to the benefits for teachers or students of increased engagement through teaching with a NOS approach. Deng et al. (2011) did mention this issue briefly when they stated that students who expressed the view that knowledge in science was tentative were more likely to be strongly motivated to improve their science knowledge. Support for this connection also came from Allchin et al. (2014) who found links between student engagement and NOS instruction while working with experienced science teachers in Danish high schools.

Thus, while there is little research exploring the connection between NOS and engagement, there is at least a reasonable consensus regarding the tenets of NOS. Table 2.1 lists ten key NOS themes which have been drawn from the literature and appear in curriculum documents (ACARA, 2015, Ministry of Education, 2007a, 2007b). Allchin (2011) argued that lists of tenets such as those given in Table 2.1 can be detrimental to the teaching of NOS if they are treated as yet another set of facts to be learned. He suggested that they should be illustrated and interwoven into

Table 2.1

*The major tenets of NOS summarised from, Abd-El-Khalick (2012), Allchin (2011), Deng et al. (2011), Lederman (2007), McComas et al. (1998), McComas and Nouri (2016), and Osborne et al. (2003a).*

<b>NOS</b>	<b>Naive/inadequate</b>	<b>Sophisticated/adequate</b>
Tentative	Scientific knowledge is fixed, facts are known, theories are unchanging	Knowledge is tentative but stable. Theories are supported by evidence but subject to challenge and change
Empirically based	Treats all science as truth or facts, whether directly observed or postulated as theories	Based on observation and data but dependant on the instruments and methods of data collection
Scientific method and critical testing	One standard way of conducting experiments	Many ways of answering questions, but methods must be sound, repeatable and subject to peer review.
Subjective/theory laden	Scientists unaffected by personal background. Investigation starts with neutral observations	Scientists' background, prior knowledge and theories, influence what, how and why investigations are carried out.
Creativity and imagination	No creativity or imagination required in science. Science follows rigid procedure.	Science is highly creative and imaginative in many areas: formulating ideas or hypotheses, experiment design and communication of findings

Table 2.1 continued

*The major tenets of NOS*

<b>NOS</b>	<b>Naive/Inadequate</b>	<b>Sophisticated/adequate</b>
Socially/culturally embedded	Science unaffected by social or cultural factors.	Science influences and shapes society and culture, and vice versa.
Observation v inference	Does not distinguish between direct observations and the inferences made from these.	Recognises that it is possible for different scientists to legitimately come to different conclusions based on the same data.
Theories v Laws	Hierarchical, with laws of higher value. Theories can become laws with sufficient evidence.	Different kinds of knowledge. Laws are descriptive statements of observations while theories are attempts to explain phenomena.
Argumentation	Justifies inferences through simple statements and repetition of standard positions. Individuals see their experiments as valid without reference to others.	Inferences justified through sound reasoning with a strong grasp of practice. Claims are negotiated and verified through argument within the relevant science community.
Cooperation and collaboration	Scientists work alone. Explanations and theories are usually produced by brilliant individuals.	Scientists work collaboratively to develop new ideas. They cooperate in order to carry out practical research and to share and critique the knowledge produced.

examples that encourage students to see the complexity of NOS. However, Allchin still produced an extensive list of NOS ideas, such as observations being subject to different inferences, and the importance of the social interactions between scientists to ensure reliability of conclusions through peer review. The NOS tenet, argumentation, is included in Table 2.1, as it incorporates many of these ideas, including peer review, and as Deng et al. (2011) concluded, argumentation is crucial for students to gain a sophisticated understanding of NOS. Lederman (2007) too, while describing only six key NOS themes emphasised that they are not separate ideas, but support each other, leading to a sophisticated view of science, especially when delivered to students through the context of scientific investigations.

### **2.3 Nature of science, scientific inquiry and engagement**

The differences between NOS and SI, as well as their relative significance, have been thoroughly debated and discussed over many years, with Crawford (2014) providing a detailed summary of the arguments. It is not the intention of this review to examine scientific inquiry in detail; however, a brief overview of the relationship between NOS and SI will enable their effects on student engagement to be examined.

As Osborne (2014a) stated, it makes intuitive sense to teach science by doing inquiry through experiments, in the same way as learning to drive a car requires practice in driving. Teachers have readily subscribed to this view as students consistently report enjoying practical activities (Osborne et al., 2003b; Varley, Murphy, & Veale, 2013), and practicals appear to address the NOS and SI requirements asked of them in curriculum documents. However, merely doing practical work falls a long way short of what is required to give students a genuine understanding of SI or NOS (Lederman & Lederman, 2014).

There have been many attempts to define exactly what makes up SI. Gagné (1963) presented a detailed analysis of inquiry, and strongly supported its inclusion at all levels of the education system. He saw the capability to carry out scientific inquiry as the end point of significant instruction over the years of schooling and undergraduate work. This instruction consisted of three parts: the practice of inquiry; the capability

to generalise knowledge to new situations; and the ability to discriminate between probable and improbable solutions or applications of science.

Thus, Gagné's description of inquiry bears a strong resemblance to modern views of NOS. It is a complex system which assumes that a person's level of scientific knowledge will influence all aspects of the inquiry, from how an initial question is framed to how the results are interpreted. Gagné suggested that in order to carry out inquiry as a scientist, a series of steps could be put in place from kindergarten to university level, gradually adding the skills needed. At the early stages, children need to learn how to observe, measure, describe and infer scientifically, as well as be able to manipulate scientific apparatus. These specific skills Gagné described as capabilities. Interestingly, Abd-El-Khalick (2012) argued for a similar approach to be taken with NOS concepts. That is, introducing simple observations in elementary school, gradually building to deeper understanding as students move through the school system, to the point where the impact of preconceived theories on those observations could be discussed.

Without these and other key steps, which build towards a student being an 'independent investigator', Gagné (1963) argued there is a danger that full inquiry could be presented too early, resulting in either failure to achieve anything, or merely to produce trivial or even ridiculous outcomes. On the other hand, the capabilities students developed should be able to be used in situations outside of science and be relevant for the rest of their lives. These capabilities and the need for structured success accords well with the suggestion by Newman et al. (1992) that the desire to be competent is a strong driver of student engagement.

Another early attempt to describe and justify the need for SI to be taught in schools was made by Schwab (1960). His vision for school science was based on SI, which involved posing open-ended questions requiring practical investigation, but mediated by discussion and debate at all stages of the inquiry. This description of SI clearly includes many NOS themes in the process. Schwab advocated that if school science was carried out in this way it would reflect a more authentic version of science, and students would be more motivated to learn. Not only that, but it would equip the

majority of students for lifelong learning, a goal of many current government initiatives (Ministry of Education, 2007a; National Research Council, 2012).

Unfortunately, the attempts to change teacher practice and implement SI in science classrooms met with limited success. Hodson (1988), saw a fundamental problem of curriculum design at the time as confusing ‘science as inquiry’ with ‘science by inquiry’. That is, by placing the emphasis on the process and methods of science, teachers, and therefore students, stuck to mainly inductive reasoning based on empirical observations. Carey et al. (1989) also viewed SI at the time as being concerned with the *processes* of science such as observing, measuring and controlling variables in experiments. Thus students were still being presented with a false view of science, and missing out on the more engaging aspects related to authentic problem solving and relevance to the real world.

The need to integrate science as inquiry with NOS and science content appear consistently in science education research. Matthews (1989) described many of the science curricula introduced over the preceding thirty years as encouraging the ‘Inquiry Method’. This was to counteract the heavily transmissive style of science teaching which presented science as a body of facts to be memorised, and was blamed for the decline in student numbers taking science. By doing experiments, making their own observations and formulating their own explanations through guided induction, it was hoped that students would be both more interested in science and gain a deeper understanding. However, this inquiry approach too failed to deliver the expected outcomes, with the problems concerning falling numbers and interest in science still being voiced.

In a review of practical science, Hodson (1996) described three approaches to science education which had been implemented in the United Kingdom and America from the 1960s to 1990s: discovery to mimic scientific inquiry; science as a process; and constructivism. Hodson criticised inquiry as a route to discovering concepts in science as flawed, from both a philosophical and pedagogical viewpoint. He noted that from a practical perspective in the classroom, it is impossible for all the children in a class to discover the correct scientific explanation for whatever phenomena they are observing or investigating through this type of inquiry. Hodson was equally

critical of the radical constructivist approach to inquiry, where children are encouraged to make sense of the world around them. He argued that this could lead to child-like common sense explanations, whereas many scientific explanations are counter-intuitive and require a significant amount of prior knowledge before they can be understood. Thus, without integrating the thinking that comes with an understanding of NOS with any inquiry, the results can be unsatisfying and lead to unease about learning in science, rather than engagement.

Support for the integration of NOS and inquiry continued in the 21<sup>st</sup> century. Lederman and Lederman (2012) made a clear distinction between science as inquiry and NOS, but also acknowledged that there are significant overlaps. They re-iterated the three ways of looking at science as described by Hodson (1996): as a body of knowledge or content; as a process or way of doing; and thirdly as a way of knowing or epistemology of science. Lederman and Lederman argued that all three must necessarily be present for a student to make any meaningful progress in science. Although the steps of science as inquiry, the processes, can be taught independently, the most effective learning occurs when students use their existing knowledge (content) and think about how and why they are doing their inquiry or investigation. This view fits well with Gagné's (1963) idea of capabilities which can be learned and practiced, building to produce a scientist who is able to carry out genuine scientific inquiry.

Others too continued to highlight both the differences yet interconnectedness of NOS and SI. Grandy and Duschl, (2007) reported that a conference of science educators and philosophers agreed on a list of some thirty aspects that made up contemporary SI. They argued that inquiry should not be carried out in some mechanical fashion as in much of school science, but required deep thinking about the processes. Their aspects showed considerable crossover with lists describing NOS, including items such as 'discussing theories/models' as well as the more traditional SI descriptor 'designing experiments'. Ford (2008) suggested that one way of viewing the difference between SI and NOS was that the former can be conceived as an ability, with students *doing* inquiry, while the latter can be seen as knowledge *about* inquiry. He argued that the two are interwoven and that in order to achieve the goal of informed citizens, students need to gain a 'grasp of practice': that is, to be able to use

both NOS and inquiry knowledge to construct and critique claims. Abd-El-Khalick (2012) also argued strongly that it is important to view SI and NOS as distinct in order to teach both effectively. He noted that describing the actual practice of scientists helps understand what doing science entails, but students will not pick up the valuable NOS knowledge just by following these practices.

One study which illustrated the difficult and complex requirements of inquiry-based learning for the hard-pressed science teacher, was conducted by Kock, Taconis, Bolhuis and Gravemeijer (2013). A unit of work on electricity for a Year 9 class in the Netherlands was specifically developed with the collaborative open-ended, but supported inquiry model of learning recommended by much of the research literature. The expectation was that the sense of ownership of the investigation would boost both the students' understanding and engagement. However, neither of these outcomes were achieved to the level expected. Three reasons were suggested for the disappointing results. First, the experimental tasks were so open that many students failed to gather meaningful data. Second, the students needed a theoretical framework in order to make sense of their data, and third, students were not used to this culture of open inquiry and were more interested in completing the task in their usual manner. Added to this was the realisation that the whole exercise was complex and demanding for the teacher, who had to make sure the physical resources worked, and guide the students without providing 'the answers'.

Two excellent summaries of the debate over NOS and SI by Osborne (2014a) and Crawford (2014) both concluded that although there may still be confusion over the terminology used, there was consensus over the intent for their use in classrooms. Inquiry and NOS need to be interwoven and made explicit when even the simplest of tasks are performed. For example, teachers commonly ask students to find the boiling point of water with the belief that by *doing* science students will learn *about* science and enjoy the experience. However, students may become disengaged if they see the procedure as trivial, not representing real science. Combining NOS and SI can help students understand how and why science works, think critically, and apply this knowledge in their daily lives, factors that have been shown to increase engagement (Cornelius-White, 2007; Sawyer, 2006).

## **2.4 Measurement of NOS and engagement**

### **2.4.1 Introduction**

There are two powerful reasons for assessment of NOS in science classrooms related to engagement of students; to provide feedback on student learning, and to provide an extrinsic reward for including NOS. Hattie (2003) identified feedback as the most important technique teachers can use to improve learning outcomes, stating that it must be specific, and provide the ‘next steps’ in the learning process. To do this, information is needed by the teacher about the student’s progress, so some type of formative assessment is required. This enables students to gain an appreciation of their level of competence concerning NOS, and knowledge of the steps needed to improve, a key part of intrinsic motivation (Reeve, 2012).

The second reason is to send a signal to teachers, students and parents that NOS is a valued part of the curriculum, thus providing extrinsic motivation to both student and teacher. Intrinsic and extrinsic motivation play large roles in the engagement of students in the classroom (Newman, 1992), so it is very important that assessment of NOS is easy to manage, and is designed to produce reliable information of immediate use to teachers and students.

However, before NOS assessment can be used as a tool for teachers to help motivate and engage students, the teachers themselves must have good NOS knowledge. Finding out the degree of NOS knowledge of high school teachers and students has been the goal of much educational research over the last fifty years, with the same tools often used for both groups. There have been some comprehensive reviews of instruments for assessing conceptions of NOS (Lederman, Wade, & Bell, 1998; Lederman, 2007) but a brief examination of some instruments can help reveal how they might be of use for teachers to improve the learning of NOS concepts in the classroom, and hence increase the engagement of students.

## 2.4.2 Development of NOS instruments

One of the earliest attempts to measure NOS concepts was described by Davis (1935) who developed an instrument with the expressed intent of improving the teaching of NOS. He called this a measure of ‘scientific attitudes’, but many of these attitudes were what would now be regarded as NOS, such as the “willingness to change opinion on the basis of new evidence” and the “ability to distinguish between fact and theory” (Davis, 1935, p. 117). As with many future NOS assessments, banks of statements were created for each attribute with students asked to select from a range of possible reasons supporting each statement. As well as focussing on how well the students’ answers agreed with accepted views, Davis was keen to develop questions that assessed the students’ ability to apply NOS knowledge to practical situations. The intent of this assessment tool was therefore to encourage teachers to present science to their students as relevant and applicable to their lives, not just a list of facts to remember. In other words, to value NOS and use this to engage students

Another early instrument demonstrated some of the features of quantitative research techniques that became heavily criticised in later years. Wilson (1954) provided a set of twenty-six statements in order to find out if the stated intentions of science curricula, such as promoting critical thinking, were being taught. Participants were required to indicate if some statements were true or false, or they agreed or disagreed with other statements. The statements consisted of a mixture of attitudes towards science and an understanding of scientific method and process. The same set of questions was given to teachers, high school and university students, and included ones with lengthy and difficult wording such as (Wilson, 1954, p. 160):

The exactness and impartiality of the scientist in performing and reporting laboratory experiments is probably due in large part to the knowledge that his work will be examined by other competent workers rather than to the fact that scientists are more impartial and objective than other men.

Several difficulties emerged from this type of test item, all noted by subsequent researchers and assessment designers (Aikenhead & Ryan, 1992; Lederman, 2007;

Rubba & Anderson, 1978). First, it is vital that the language used be accessible and appropriate for the target group; thus wording should be simplified for younger students. Second, allowing only a true/false or agree/disagree response forces participants into expressing an extreme view, when their actual opinion may lie on a continuum between these points. Third, the designers of the question had a particular view in mind when they constructed the item, but this interpretation may not be shared by the participants.

A very early recognition of the limitations of quantitative measurements prompted Mead and Métraux (1957) to carry out a qualitative investigation to find out what images American high school students held about science and scientists. This extensive, very open-ended project was conducted by asking high school students to write paragraph responses to incomplete statements such as: “When I think about a scientist, I think of ... “(Mead & Métraux, p. 385). The authors’ analysis of the responses was incredibly time-consuming, a characteristic of qualitative research that makes this technique impractical for the classroom teacher. However, it did deliver the benefits of qualitative work, providing rich descriptions revealing a great range of views, sometimes showing that contradictory opinions can be simultaneously held. For example, many girls expressed positive views about scientists and the role of science in general, but were very negative when it came to personal decisions, such as becoming a scientist or marrying one. The clear advantage for any teacher allowing this type of free response is that they could collect powerful messages about the emotional state of their students in relation to their teaching. In summarising their research the boredom expressed by many students in their science lessons was noted, with some even expressing feelings “of fury and hatred of particular activities” (Mead and Métraux, 1957, p. 388). Conversely, they noted that students who enjoyed science were actively involved, working with their teacher, and saw science as part of their lives. This type of feedback provided valuable information that teachers could use to engage their students with science, or at least counter some of the noted disenchantment.

In order to collect the fine detail useful for feedback in a timely and cost-effective manner, Cooley and Klopfer (1963) developed the Test for Understanding Science (TOUS), consisting of sixty multiple-choice questions. They recognised that to

measure the effectiveness of new teaching strategies or materials, specific tests must be developed which actually measure the intended objectives of that strategy. Their teaching intervention was to use case studies taken from the history of science to try and improve students' understanding of NOS (Klopfer & Cooley, 1963). They wanted feedback on the effectiveness of their course in improving students' NOS knowledge and whether it affected student achievement in the usual content-oriented tests. If they could show positive outcomes for NOS knowledge without negative effects on achievement in regular tests, this would help convince and motivate teachers to use the history of science strategies.

The steps outlined by Cooley and Klopfer (1963) set the pattern used by many future researchers when developing instruments for assessing NOS understanding. First, they formulated and made explicit the key NOS themes which were to be assessed through discussions with science educators, scientists and philosophers of science. Then a bank of 200 multiple-choice questions was created based on the eighteen themes that emerged from those discussions. The questions were reviewed, altered by experts, and reduced to 120 in number. These were then trialled with suitable samples of students and statistical techniques applied to determine which questions were most effective in ascertaining the genuine views of the respondents. A final version of the instrument was then produced, containing only the most fruitful items and this was used before and after a teaching intervention to measure any changes. Cooley and Klopfer acknowledged that the construction of a new instrument was a long and difficult process, but this gave teachers and researchers confidence in its validity.

A variety of instruments measuring aspects of NOS similar to TOUS were reviewed by Aikenhead (1973), who noted that although these tools did at least permit the measurement of an important part of science education, there were still significant problems. These included the difficulty of interpreting a single score for NOS knowledge, a suggestion being that using a set of subscales revealed more useful information. Other problems noted were: the use of material with an inappropriate reading level for some students; the confusion between attitudes towards science and understanding of NOS; and the excessive number of items in some surveys. A major disappointment was that in many research studies using these instruments, little or no

improvement in NOS knowledge was detected, perhaps indicating the instruments were not appropriate. Aikenhead suggested that a way forward might be to include a qualitative dimension to research designs in order to gain some insights into what participants were actually thinking and feeling, so that specific interventions to address these could be developed.

Nevertheless, due to the attractions of quantitative data collection in providing cheap, quick assessments of NOS, further attempts were made to produce surveys which addressed the continuing criticisms. Rubba and Anderson (1978) gave a detailed account of the seven steps required to produce a new instrument called the Nature of Scientific Knowledge Scale (NSKS). One method they claimed would ensure the validity of the instrument was both to formulate and cross-check the items with philosophers of science and scientists, surely a problem in itself given the lack of a consensus regarding NOS at the time, as noted in Section 2.2.1. Another improvement suggested by Rubba and Anderson (1978), was to check that the reading level was suitable for junior high school students. Fraser (1978b) too, extensively modified the language to make a version of the TOUS specifically tailored for upper primary and junior high school students.

Even these measures did not go far enough for Aikenhead and Ryan (1992), who developed a completely new type of instrument called Views on Science-Technology-Society (VOSTS) to address two major validity problems with existing instruments, problems also identified by others (Cotham & Smith, 1981; Rowel & Cawthorn, 1982). First, the ambiguity created by researchers when writing questions or statements meant that they could be interpreted differently by students. Second, restricting the choices available as answers, made it almost impossible to determine students' actual views. Aikenhead and Ryan solved these problems by creating items and responses derived from high school students themselves, using paragraph answers and semi-structured interviews to produce between five and thirteen possible responses. They suggested that VOSTS be used in a diagnostic way by teachers, to find out students' preconceptions, rather than as a tool for assigning a score which supposedly represented their NOS knowledge. Alternatively, it could be used to initiate class discussions about socioscientific issues, with teachers selecting appropriate items from the VOSTS bank as a way of teaching and reflecting on NOS.

Either way, the instrument could be useful for teachers to engage students as it provided clear examples of NOS in contexts relevant to the students, written in a way they could understand.

Despite the improvements in quantitative instruments, there was a growing realisation that a deeper understanding of students' views concerning NOS concepts would be useful, and could be ascertained more effectively using qualitative techniques. Miller (1983) noted that interviews were used as far back as 1957 to flesh out data collected in a national survey on attitudes towards science. Carey et al. (1989), strongly advocated the use of interviews as a valid way to collect the views of students about NOS. They argued that the multiple-choice (TOUS) and graded response surveys (NSKS) in use at the time, placed constraints on students' initial conceptions and did not enable their understanding of terminology to be probed. Even Aikenhead and Ryan (1992), in designing VOST, accepted that semi-structured interviews provided the most reliable way of overcoming the validity problems of quantitative instruments.

One way of combining quantitative and qualitative techniques used to investigate NOS in a rural high school was described by Lederman and O'Malley (1990). They used just seven questions in an instrument subsequently called VNOS-A (Views of Nature of Science – Form A) to elicit open-ended written responses, supported by semi-structured interviews, to check whether the written answers and their interpretations were valid representations of students' views. In many of the cases the initial views were confirmed, but the process did reveal one area of significant misunderstanding concerning the use of the word *prove*. The researchers interpreted the use of this word to mean the students had an absolutist view of NOS, but during interviews it was clear that the students supported a more tentative view, in the sense of experimental evidence supporting rather than proving absolutely a particular theory or law.

The problem of researchers misinterpreting responses in questionnaires was also noted by Tobin and McRobbie (1997) who used extensive interviews and classroom observations to corroborate questionnaire data. As a consequence of this kind of corroboration Lederman and O'Malley (1990) completely discounted information

from three items on their VNOS-A questionnaire. If the information from any type of measurement of NOS understanding is to be useful in informing teacher practice, then it must accurately represent what it purports to measure. However, the use of thirty minute interviews to assess NOS knowledge for each student is unrealistic for a classroom teacher, even if the results provide the best possible information for future teaching and learning.

Further versions of the VNOS instrument were developed (Lederman et al., 2002; Lederman, 2007) in order to improve the validity of some questions and to tailor them to specific age groups. With these refinements, Lederman et al. (2002) found that there was no need to interview every participant, as the written answers provided a reliable profile in most cases. However, interviews were still recommended to provide the detailed profiles of NOS understanding that would provide insights needed to direct teaching and learning. Several examples of these insights were given by Lederman and O'Malley (1990). First, the inability of students to identify when and where their NOS beliefs originated indicated there was no explicit instruction of NOS in school. Second, students did not see laboratory experiments as a good way to learn about NOS as the outcomes were usually already fixed, reducing the incentive to carry them out. Such insights should encourage teachers to move away from recipe-type activities towards more open-ended investigations which are more engaging as they are more authentic and give students a sense of agency and discovery. Finally, the students recognised that they needed significant content knowledge in order to appreciate the changes in science ideas that lead to a tentative view of science. Again, useful feedback for teachers who can be reassured that content is still valued, but must be integrated with NOS to promote learning in both areas.

The VNOS instruments have continued to be used by many researchers (Bell et al., 2011; Khishfe & Lederman, 2007; Rudge, Cassidy, Fulford, & Howe, 2014; Yacoubian & BouJaoude, 2010) in modified forms for a variety of learners, including pre-service teachers, middle and high school students. They have been mainly used by educational researchers rather than classroom teachers, and increasingly used along with interviews to ascertain which instructional techniques contribute to the most shifts in students' thinking about NOS. Valuable feedback has

been obtained, but these instruments are still time-consuming for teachers to use in busy classrooms.

There have also been several researchers who, for a number of reasons, have continued to use and develop quantitative instruments. Martin-Dunlop (2013) chose to use the NSKS to measure the level of NOS knowledge in pre-service elementary teachers. This was done in conjunction with a quantitative instrument focused on the learning environment, in order to search for links between the two using inferential statistics. Interestingly Martin-Dunlop also used semi-structured interviews to validate the findings. The desire to apply sophisticated statistical analysis was also a major factor in the development of a new quantitative instrument called the Chinese Scientific Epistemological Views (CSEV) by Chai, Deng and Tsai (2012). Chen et al. (2013) developed another questionnaire called Students' Ideas about Nature of Science (SINOS), again to be able to apply statistical techniques to large data sets, the advantages being speed of processing and cost effectiveness. The authors did however, acknowledge that a classroom teacher would only gain a rough guide of their students' NOS knowledge through this instrument, but could supplement it with interviews to generate strategies that addressed any misconceptions.

### **2.4.3 Classroom assessment of student NOS knowledge**

As described in the preceding section and as Allchin (2011) noted, most instruments for assessing NOS knowledge have been designed for educational research and are not particularly suitable for classroom assessments of students. Therefore, they provide little help for teachers trying to engage students through NOS.

An early classroom assessment developed by Chiapetta and Koballa (2004) was simply a true-false test on some of the fundamental NOS concepts. They suggested this could be used as a quick in class test, or as a tool for facilitating discussion about specific NOS concepts. Crawford (2005) made a case for including observations of students performing tasks as a better method of assessment of science knowledge, rather than relying solely on written exercises. She found that students in a fourth-grade science class in California produced very limited written reports describing their experimental investigation. However, when asked to demonstrate their

experiment with verbal questioning, they revealed considerable NOS knowledge. This form of assessment although time-consuming for the teacher, allows students to display competence in the classroom setting, a key factor for improving engagement (Newman, 1992; Skinner & Pitzer, 2012).

Making video recordings of students for assessments was also a technique used by Crawford (2005), but this is impractical for most teachers who rely on written tests concerning NOS, as they are easier to administer and more familiar. However, finding good written tests can be problematic. Many good resources for teaching NOS have been placed online in recent years (Science Learning Hub, (n.d.); Te Kiti Ipurangi, (n.d.); Evolution and the Nature of Science Institutes, (n.d.); Understanding science: How science really works, (n.d.)), but few provide assessments to support the learning. Some merely suggest that the teacher uses the lesson objectives as assessment criteria, while most provide questions teachers could ask to guide the learning. One site that does include assessment tools and examples is Project ICAN: Inquiry, Context and Nature of Science (n.d.), the online support provided for the ICAN project described by Lederman and Lederman (2012). Here, as well as the various VNOS instruments, are sample assessments with typical student answers put in the context of classroom activities or experiments. Teachers can see specific examples of written questions they could use to both stimulate thinking about NOS, and combine with traditional content-based assessment to provide external validation and motivation for learning about NOS.

A great deal of emphasis has been placed on formative assessment in the research literature, which has been suggested is “a means of increasing student learning motivation, achievement and agency” (Cowie, 2012, p. 687). However, despite this evidence, Cowie indicated that teachers still have difficulty in using formative assessment effectively to promote learning, and so the technique is not widely used. Summative assessments dominate teacher practice in traditional areas of science content as they are required in school systems as measures of accountability. However, it seems there are few reliable and practical assessments available for NOS, although ideas abound as to how teachers could proceed. Clough and Olson (2008) noted assessment of NOS was one area still in great need of further research

and development, and Aydın et al. (2013) confirmed that this was still the case several years later.

The need for valid tools for assessment of NOS was stressed by Allchin (2011), given the current climate of accountability, noting that as NOS is in many curricula, it should be assessed. However, he argued that any assessment of NOS must be done in an authentic setting, and allow students to demonstrate their application of NOS knowledge, rather than simply recalling the key NOS tenets. Allchin created some prototype assessment tasks called KNOWS (Knowledge of the Nature of Whole Science) centred on contemporary and historical issues. Unfortunately, only a preliminary method was discussed and considerable work would be needed to implement a robust system. These open-ended problem solving tasks, developed for assessments, have also been shown to increase student engagement (Allchin et al., 2014), thus gaining the benefits of both assessing NOS and increasing engagement.

## **2.5 Teaching strategies for NOS and their effect on student engagement**

Many studies have been undertaken concerning the impact of various NOS teaching strategies on improving student understanding of NOS, but few have looked for any specific link to student engagement. In a review of 105 such empirical studies, no reference to engagement of students was made, but the authors did conclude that effective strategies “generally involve inquiry, discussion, reflection, and/or argumentation activities” (Deng et al., 2011, p. 979). As noted in Section 2.2.2, these types of activities have also been connected with positive attitudes towards science. A closer examination of some of the successful strategies for teaching NOS provides some evidence for a link between NOS and student engagement.

A study using the history of science as a teaching strategy was described by Solomon et al. (1992), which addressed students’ understanding of both NOS and science concepts. Teaching material covering thirteen topics were developed, all based around a theory that had changed. Written accounts from the past were combined with experiments the students could do in class, and students were helped to think about the processes of theory-making and testing. The results indicated that the students improved their understanding of both NOS and the science concepts in each

unit. Solomon et al. noted that the units increased the attention span of the students, a sign of increased engagement, and that the teachers became enthusiastic about this teaching approach. However, they acknowledged the impact of innovation enthusiasm from the researchers, the extra classroom help and the provision of new teaching materials, all factors that can lead to improved outcomes whatever the new strategy.

A unit of work carried out by several high school chemistry classes to teach oxidation-reduction reactions in a history of science context, was described by Allchin (1997). Although the authentic nature of the guided inquiry involved uncertainty, especially for the teacher, it gave the students a sense of ownership over their learning, a factor recognised as a key component of student engagement (Newman 1992). It was noted that as the unit progressed “our students became generally more enthusiastic and more engaged in their own learning” (Allchin, 1997, p. 492). Other strategies identified as contributing to both NOS knowledge and increased engagement, included cognitive conflict and discussion between peers. The problem with the unit however, was the major increase in workload for the teacher as many new resources had to be prepared and experiments developed.

These difficulties were also encountered by Maurines and Beaufils, when preparing units for high school teachers in France, using historical inquiry to teach NOS in a physics context. The authors developed and adapted many new activities and found that teachers needed considerable support, wanting both more historical background knowledge and specific lesson plans in order to implement the new strategies. Despite these problems, they found that “teachers report that students were interested and involved in the activity” (Maurines & Beaufils, 2013, p. 1456), indicating increased engagement.

One study that definitely did find evidence linking student engagement to strategies for teaching about NOS was carried out by Bell (2000), with middle students in California. Students had to evaluate several pieces of evidence in order to debate the question ‘how far does light go?’ taking up either a naïve, realist position or a more sophisticated NOS view concerning the answer. As well as noting improved NOS understanding as a result of the intervention, it was noted that, “students engaged in

the ‘how far . . .?’ debate enthusiastically and completed all aspects of the project” (Bell, 2000, p. 805). This high rate of task completion and obvious enjoyment are good indications of student engagement. Bell acknowledged that the two-week time commitment and preparation of the resources would present significant challenges for the average unsupported classroom teacher. However, he offered some pedagogical advice derived from this study which could be useful for science teachers contemplating this sort of activity. First, make the problem relevant to the lives of the students. Second, provide scaffolding to help students frame their ideas, in the form of hints, focussing questions and sentence starters. Finally, make individual and group thinking visible so that ideas and reflection about theories and explanations are made explicit.

One of the very few studies to specifically investigate any link between NOS views, motivation and achievement was carried out by Cavallo, Rozman, Blinckenstaff, and Walker (2003) on first and second year college students taking biology and physics courses. They found that biology students with a tentative view of NOS had a positive correlation with learning, and were motivated by the enjoyment of learning, rather than for external rewards. They also found that these students were higher achievers compared to those with a fixed, unchanging view of science knowledge.

After working with and observing a group of eleven science teachers in the United Kingdom, Bartholomew et al. (2004) proposed five dimensions of effective practice for teaching NOS. They used a variety of different activities and experiments, but the key factor was the way the teachers integrated NOS concepts with content through authentic contexts. Effective teachers not only needed to be confident in their own NOS knowledge, but had to model their own practice on NOS principles, such as encouraging inquiry and reasoning skills by using open-ended questions. This all had to be done through the use of activities that students saw as relevant and useful to them while making the NOS aspects explicit. The researchers noted that engagement of students was high when students were tackling problems where they had some ownership of the task and where the teacher had specifically prompted them to think about both the content being learned and the cognitive processes involved.

Another interesting account of a practical lesson designed to teach NOS and inquiry was given by Ford (2008), describing how a sixth-grade class were supported through an investigation to answer the question, ‘How does steepness affect speed?’ The key feature that promoted NOS understanding was the requirement for groups to come up with procedures and justify them in front of the whole class. A consensus had to be reached by the class before all groups carried on with the agreed method. This was repeated several times as different problems were encountered. The reflective manner in which this activity was run allowed coverage of NOS concepts as diverse as the myth of the scientific method, the social nature of knowledge construction, and the way that prior knowledge influences design and interpretation of experiments. Although not specifically stated, the implication was that the students were highly engaged in this task, as they were enthusiastic when given control over designing their own experiments, and their ideas and opinions were not only valued, but put into action.

Laboratory practices which included explicit reflection on NOS were also found by Yacoubian and BouJaoude (2010) to produce improved students’ NOS understanding. Simply adapting experiments normally done to include questions requiring students to discuss and reflect upon aspects of NOS, caused significant changes from inadequate to adequate views about NOS. However, not all students improved in all areas, possibly due to their lack of participation in the discussion phase. Yacoubian and BouJaoude recommended that research on the motivational aspects of the activities be conducted to see why some students were not engaged when most were actively involved.

Another study, done on a larger scale, was undertaken in Swedish high schools by Ekborg, Ottander, Silfver, and Simon (2013). They used resources about socioscientific issues in order to address several matters, including teaching NOS and improving student engagement. The teachers all agreed that stimulating students through use of relevant and authentic issues was the key to increasing student engagement and understanding of school science. They noted that most students were indeed more engaged than usual when using the new resources. This view was supported by the students themselves (Ottander & Ekborg, 2012), with the additional finding that the more interest the students reported, the more they believed they had

learned in terms of both facts and skills. However, the researchers noted little explicit discussion of NOS ideas or changes in teaching pedagogy, and found that teachers were concerned at the loss of time needed to deliver the regular content in their science courses.

In Portugal, Freire et al. (2013) analysed the effects on secondary school students who were taught using units developed as part of the PARSEL Project (Popularity and Relevance of Science Education for Scientific Literacy). As the name suggests, these units were designed to improve student engagement, and used a three-step approach incorporating some aspects of NOS. First, a social theme was chosen linked to the students' lives, then this was investigated through inquiry-based problem solving, leading finally to a decision concerning the original socioscientific issue. The results were very positive, with students indicating that they were engaged and valued the links with real issues. These views were supported by extensive interviews and classroom observations, producing comments from students such as: "They made us engaged. We learn in a different way. We become more motivated to learn science content" (Freire et al., 2013, p. 170). The authors pointed out two key components of the units that contributed to their success. First, students had to be able to plan their own experiments or inquiry to answer a specific question related to an issue that affected their lives. Second, opportunities for students to discuss and argue their case based on the evidence had to be provided. Although changes in understanding about NOS were not specifically measured, it was clear that many students gained a more realistic view about how scientists work. The authors concluded that this study should help convince Portuguese science teachers to change their practice as it demonstrated that students were engaged through use of the challenging and relevant material. This material was also successful in motivating students to learn both the regular content of science lessons and NOS, further aspects of importance to science teachers.

Finally, Allchin et al. (2014) observed a range of NOS strategies used by experienced high school teachers in Denmark. The teachers attended professional development workshops beforehand and wanted clear strategies that would work in the classroom which were focussed on functional use of NOS, rather than simply knowledge about NOS. Units of work were constructed which incorporated three different NOS

approaches: contemporary cases; inquiry-based experiments; and historical cases. Allchin et al. argued that each approach has particular advantages and disadvantages for covering the various NOS tenets, and each appealed to students in different ways. For example, contemporary cases engaged students through their immediate relevance but could be frustrating as there was often no resolution of the issue due to their complex and ongoing nature. The techniques used within these units were based on well-established practices for effective science teaching, including: framing the learning as problems; providing scaffolding for inquiry and thinking tasks; and explicit reflection about NOS concepts in collaborative situations. One unit on the use of vitamins seemed particularly successful, drawing many positive comments from teachers related to student engagement: “The students were very motivated. They could relate to the topic personally ...”, and “The students have been very engaged and well-prepared for the group work ...” (Allchin et al., 2014, p. 479). The key message from this study was that both NOS and regular content could be integrated in ways that improved student engagement in a normal school science environment.

Thus, it appears that there are many well documented teaching strategies available in the research literature indicating that teaching NOS can increase the engagement of students in school science. However, few attempts have been made to specifically link changes in NOS knowledge with the level of student engagement. Fortunately, there seems to be agreement over which strategies are successful, with many studies recommending similar teaching pedagogies, as summarised in Appendix I. The challenge is to extend these strategies beyond the group of enthusiastic science teachers and researchers involved in these research projects. If the majority of science teachers could be persuaded to try these proven approaches, then a genuine widespread improvement in NOS understanding could be achieved. At the same time, both teachers and students could be more engaged in science, enjoy their shared experience, and become better equipped to tackle the challenges of the 21<sup>st</sup> century.

## **2.6 Chapter summary**

The overwhelming impression from reviewing research on NOS is that its inclusion in school science has had strong support for many years, from a wide variety of

groups, including science educators, government agencies, philosophers and historians of science as well as scientists themselves. Some of the reasons given for supporting the teaching of NOS have been to:

- produce informed citizens who are scientifically literate so they can make evidence-based decisions in both their personal lives and as part of democratic communities.
- deepen students' understanding of science content.
- encourage students to continue studying science-related courses.
- gain valuable thinking skills applicable to their future lives in any field.
- gain an appreciation of the role and importance of science in modern technological societies.
- make learning science more engaging and equitable, thus encouraging participation in science from people with diverse backgrounds.

Despite all these excellent reasons for NOS to be included in school science, many studies continue to report low levels of NOS understanding amongst both students and teachers, and continuing use of traditional teaching methods in science classes. However, with a clear list of NOS tenets now generally accepted and many effective teaching strategies identified, it has been shown that large improvements in NOS knowledge are possible.

In concluding a review of NOS Lederman (2007), asked how science teachers could be persuaded to value NOS as highly as content knowledge. I believe the answer lies in demonstrating to teachers that by using a NOS approach, students will be more engaged in class and that science content will be better understood. This will only be possible for busy classroom teachers if they are given on-going support of the sort and scale outlined by Lederman and Lederman (2012), so that they gain sufficient PCK to be able to teach NOS with confidence. Chapter 3 reviews the literature around engagement of students with school and science, to explore the links between NOS and engagement. It also provides an analysis of the reasons for the inclusion of NOS in current curriculum documents, and whether this has actually resulted in the delivery of NOS in the classroom.

## **CHAPTER THREE      Literature review on student engagement and curriculum implementation related to NOS**

### **3.1 Introduction**

This chapter continues the review of the literature concerning NOS, focussing on student engagement and science curriculum implementation. The aim of the research component of this thesis is to investigate the link between teaching with a NOS approach and any engagement of students this might produce. Thus, the first part of this chapter consists of a review of the literature related to the engagement of students in school, with science and NOS. The second part, Section 3.3, consists of a review of the literature concerning the design and implementation of science curricula around the world, and their effect on the engagement of students.

### **3.2 Student engagement with school, science and NOS**

Engagement of students with secondary schooling is a relatively new field for educational research, with Mosher and McGowan (1985) finding no previous work explicitly conceptualizing or measuring engagement in this area. Fredericks et al. (2004) noted, in proposing a comprehensive theory regarding engagement, relevant research came from a wide range of fields including: student attitudes; task oriented behaviour; and motivational theory. The driving force for much of the early work seems to have been concern over disengagement of students, with studies investigating why students were switching off, or even dropping out of school altogether (Finn, 1989; Newman, 1992). Concerns have also been expressed about the drop in numbers choosing senior sciences and science careers, as well as the disengagement of many students in school science classes (Bull et al., 2010; Tytler et al., 2008). As argued in Section 2.1, using NOS to improve student engagement appears to have merit, an idea supported by Bolstad and Hipkins (2008). However, a closer examination of the research on engagement is needed in order to make an informed evaluation of the links between NOS and engagement.

### 3.2.1 Theories of engagement and implications for NOS

In one of the first major reviews of the literature concerning general student engagement in schools, Mosher and McGowan (1985) reported that the concept had not been clearly defined, but was generally viewed in terms of students participating in some aspect of schooling. Early research focused on disengagement, especially those who dropped out of school, and revealed there were many influences causing this disengagement with school. Having scoured the sparse literature, Mosher and McGowan offered three initial suggestions concerning engagement. First, engagement could be viewed as both an attitude and an action, with the thought processes of a student leading to participation in school activities. Second, levels of engagement were determined by many interacting factors, such as societal expectations, home background, type of school, as well as individual personality traits. Third, the level of student engagement could influence many different outcomes, not just achievement, such as behaviour in class and social interactions in different situations.

The factors that influenced student engagement, and therefore student outcomes, were discussed by Mosher and McGowan (1985). Some of these were beyond the control of classroom science teachers, but several were of considerable relevance, especially to those teaching NOS. For example, students who were given more opportunities to participate in class and received immediate feedback were more satisfied with school, as were those who felt they had some control over their learning. These are all important strategies recognised for effective NOS teaching, as described in Section 2.5.

Although much of the early literature did not use the term ‘engagement’, there was considerable work being done around the factors that motivated students. Dweck and Leggett (1988) suggested a social-cognitive approach to motivation where a student’s type of goal setting influenced their subsequent behaviour. The authors identified two types of goals, *performance* and *learning*, which were dependent on an individual’s theories about intelligence. If a person had the view that their level of intelligence was fixed, then they tended to adopt performance goals. Dweck and Leggett found these students did not seek challenging tasks and quickly gave up, or

disengaged with tasks when they met with failure. Conversely, those students with the view that one's intelligence could be improved, adopted learning oriented goals with the aim of mastering tasks, thus increasing their competence. These students often relished challenges, gained satisfaction from tackling difficult problems and persevered when encountering initial failures. These cognitive and behavioural effects soon manifested themselves as emotions, with those pursuing performance goals exhibiting boredom or anxiety, finding ways to distract themselves and disengage from difficult tasks. Whereas, those students adopting learning goals became more engaged with the problem, seeming to enjoy the challenges presented.

Influencing a person's disposition towards learning or performance goals was discussed by Dweck and Leggett (1988), who suggested that these dispositions, and therefore engagement with tasks, could be altered by situational variables. The implications of this theory of motivation are clear for the classroom teacher. If a classroom environment is established that values mastery learning, encourages problem solving and where it is safe to 'fail', then students will favour learning goals and so be more likely to engage with challenging tasks. These are exactly the characteristics identified as promoting learning of NOS and which many see as essential for students to have as they face the challenges, uncertainties and rapid change of the 21<sup>st</sup> century (Gluckman, 2011; Robinson, 2011).

Emerging neuro-science and epigenetic research (Doidge, 2010; Shenk, 2010; Willingham, 2009) also supported the idea that intelligence and other personal traits are not fixed, overturning the long-accepted theory that you are born with a certain intelligence which cannot be altered. This also illustrates the tentative NOS which teachers could use to motivate and engage students; if ideas can change in science then so can ideas about yourself. By encouraging students to adopt learning oriented goals instead of performance goals, students should be able to adopt more positive attitudes to learning and develop the competencies and confidence to tackle the challenges in their lives.

One study that looked at student disengagement with school (Finn, 1989), also suggested some ways that students could be encouraged to stay in the system by increasing engagement. Finn's *participation-identification* model was presented as a

way of explaining pathways that led to students dropping out, with *identification* referring to a student's commitment to school, both in the cognitive sense of valuing what it has to offer and an emotional sense of belonging. It is the *participation* aspect of the model that a classroom teacher, especially if using a NOS approach, could directly influence.

The argument proposed by Finn (1989), was that increased participation in class produced improved academic performance, and that this improved student self-esteem, therefore encouraging further engagement. He stated, "It is clear that students who exhibit problem behavior feel alienated by a curriculum that is irrelevant to their needs" (Finn, 1989, p. 129). If science teachers can be shown that the NOS strategies such as discussion and argumentation about students' own investigations reduce problem behaviour and increase performance, then they are more likely to include these strategies in their own repertoire. Interestingly in the New Zealand curriculum *participating and contributing* is listed as one of four aspects making up the NOS strand with an associated learning objective for students in junior high school to, "Use their growing science knowledge when considering issues of concern to them" (Ministry of Education, 2007b, p. 45). This is an objective that Finn's research indicated would improve student engagement.

Another project which addressed multiple problems, including high drop-out rates, low levels of achievement, and low emphasis on higher-order thinking in American high schools, concluded that student engagement was the key factor necessary to produce significant change (Newman, 1992). Newman identified disengagement of students with school as the most important issue facing secondary education and provided an excellent description of students who are engaged:

... engaged students make a psychological investment in learning. They try hard to learn what school offers. They take pride not simply in earning the formal indicators of success (grades), but in understanding the material and incorporating or internalizing it in their lives (Newman, 1992, p.3).

These are the sorts of students every teacher wants in their class, and the outcomes every science educator or curriculum writer is aiming for regarding NOS

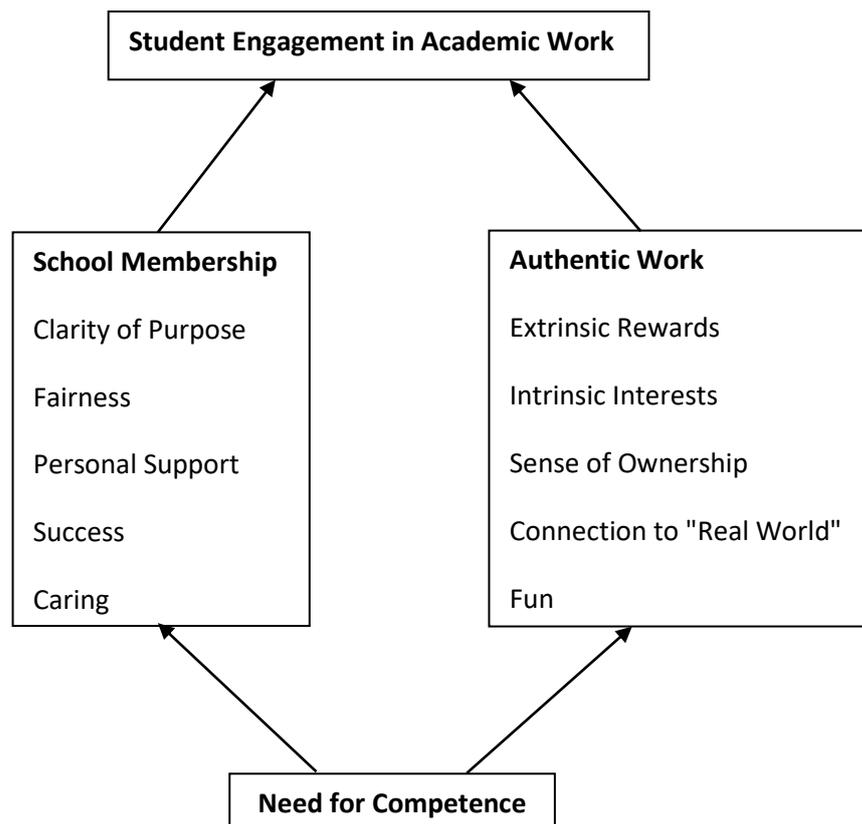
implementation. Newman strongly asserted that learning only occurred when the student was prepared to put in the effort to complete tasks, to be persistent and learn from mistakes, and this only happened when they were fully engaged.

Having recognised from the study of effective secondary schools that there are many factors related to engagement beyond the control of the school, Newman et al. (1992) went on to explain what schools and teachers could do in order to engage their students in academic work. They explained the impact of student engagement on academic work in terms of three main factors, as summarised in Figure 3.1. Two of these, the need for competence and authentic work, merit closer inspection as they have strong links to many aspects of NOS. The third factor, a need for a sense of belonging as a member of the school, is generally out of the control of the individual classroom science teacher.

The production of competent citizens able to make informed decisions has been a desired outcome for school science education in many countries. In New Zealand, the national curriculum even specifies five key competencies, including managing self, relating to others, and thinking (Ministry of Education, 2007a). These competencies have been linked directly to five NOS ‘capabilities’, which include interpreting data from observations, and gathering and critiquing evidence (Hipkins, 2013). Gagné (1963) also emphasised the need for competence, describing the key steps in scientific inquiry as competencies (see Section 2.2.2). He claimed that if they were not mastered early on, students were unlikely to continue with science. The importance of competency for producing engagement was well summed up by Newman et al. (1992, p. 19):

Achieving cognitive understanding and mastery – getting it right – are personally rewarding, especially as they enable people to have some impact on the world. The need for competence has been recognized as one of the most powerful bases for human action and motivation.

So, if effective teaching strategies for NOS are put in place, then students should feel more competent and increase their engagement with science.



*Figure 3.1*

Factors that influence student engagement in academic work, Newman et al. (1992).

The points made by Newman et al. (1992), linking authentic work to student engagement, are very similar to those made by many researchers concerning effective teaching of NOS (Allchin et al., 2014; Lederman, 2007). First, the material must be presented in ways that capture student interest, through problem solving and opportunities to reflect on the meaning and relevance of NOS to the student. Second, when students have some choice about their work when carrying out scientific investigations, they develop a sense of ownership which increases their engagement. Finally, connections to the real world are vital to create authentic learning experiences, as when NOS principles are applied to complex contemporary issues. Newman et al. (1992) extended the idea of authenticity to other aspects of life encountered outside of school. For example, people in work usually receive quick and accurate feedback about their performance, and often collaborate on projects. These are also aspects that represent good NOS practice, modelling the way scientists work together on experiments and gaining feedback through peer review.

The links between cognitive engagement and students' motivation were explored by Pintrich et al. (1993) in the context of conceptual change, an area relevant to many aspects of NOS. They found that tasks which were challenging, authentic and relevant to the lives of students beyond school, promoted the adoption of mastery or intrinsic learning goals. These encouraged students to think more deeply, reflect on their learning and increased their engagement with the tasks. These same strategies were found to be effective for teaching NOS, motivating students and producing conceptual change (Allchin et al., 2014; Meyling, 1997).

Another finding from Pintrich et al. (1993), was that students who perceived they had some control over their own learning boosted their intrinsic motivation, increased their effort and hence improved their performance. The authors noted that inquiry-based activities such as described in Section 2.3 for NOS instruction, were well suited for improving the motivation of students and hence increasing their engagement in class. However, this required skilled teachers who were prepared to allow the students a degree of choice, while still providing the structure and support needed for them to succeed. Deficiencies in these skills and a reluctance to try new approaches were also identified as problems for teachers in delivering effective lessons incorporating NOS.

In an attempt to bring the various strands of research on engagement together, Fredericks et al. (2004) defined engagement in terms of three components: behavioural, emotional and cognitive. Behavioural engagement extended from merely passive participation in school and class activities, to more active involvement such as asking questions and seeking answers. Emotional engagement encompassed all the feelings a student had towards their teachers, peers and activities in class. These emotions could range from excitement and interest, to boredom, or even fear. Finally, cognitive engagement was evident when students chose effective learning strategies and were active in self-reflection. This enabled students to solve problems and persist when faced with difficulties. An advantage of looking at engagement from this multidimensional perspective was that it provided a clearer picture of the complex issues that determine an individual's level of engagement, and gave some structure to those developing appropriate strategies to improve engagement.

In summarising the research on both the products of engagement and the factors that encouraged student engagement in schools, Fredericks et al. (2004, p. 87) stated:

Engagement is associated with positive academic outcomes, including achievement and persistence in school; and it is higher in classrooms with supportive teachers and peers, challenging and authentic tasks, opportunities for choice, and sufficient structure.

These positive outcomes and the strategies for achieving them are very similar to those associated with effective NOS teaching. For example, when students carry out experiments, they should be asked to think for themselves by making a hypothesis, and have some choice over the methods used (Osbourne et al., 2003b). If teachers then explicitly point out the NOS links and explain that this is how scientists work, students should see their experiments as authentic tasks where they have an element of control, factors which should increase their engagement.

Support for these findings on the importance of engagement and the strategies needed to engage students came from a study by Wylie and Hipkins (2006). The authors concluded that “students who were engaged in school and absorbed in learning were likely to be in positive learning environments, where – there was good feedback, relevant teaching, challenging work, and a focus on learning at the students’ pace” (p, xvii). An important finding was that students’ attitudes in junior high school were not fixed and could be influenced by teachers to improve engagement. One set of data that seemed especially relevant to practicing science teachers was that about 20 per cent of students reported passive disengagement, such as getting away with doing little work, while 10 per cent claimed to be actively disruptive. If teachers could make science interesting, relevant and useful to students by using effective NOS strategies, then not only would students gain valuable science and NOS knowledge but teachers would experience greater job satisfaction and less stress caused by disruptive students.

Strong support for the idea that there are definite strategies teachers can use to engage students, came from a large scale meta-analysis of the literature related to teacher-student interactions (Cornelius-White, 2007). Cornelius-White found that

student engagement in class increased when the teachers took a learner-centred approach, which included creating a warm, caring class environment where every child is valued. More significantly for teaching of NOS, other factors such as the use of student directed activities, and the promotion of higher-order thinking skills, were found to increase students' engagement and improve their critical thinking skills and creativity. These strategies have also been shown to be effective ways of delivering NOS, for example requiring students to make their thinking visible (Bell, 2000; Ford, 2008), or through the use of open-ended questions and investigations (Bartholomew et al., 2004). The adoption of a NOS approach to managing students in a class should also produce the supportive environment in which every child's opinion is valued, that Cornelius-White found to increase engagement. The NOS theme of cooperation and collaboration requires this, as does argumentation, where every person is expected to take part in reasoned debate and have their opinions respected, but critically examined.

Further support for the use of challenging, problem solving tasks to engage students, came from Willingham (2009), a cognitive scientist, who provided evidence from neuroscience and psychology. Willingham noted that people were naturally curious and that solving problems brought pleasure. Although not fully explained, it seems that there are some chemical changes in the brain that produce sensations of satisfaction and pleasure when a person succeeds in a cognitive task or puzzle. However, people must perceive themselves as being able to solve the task in order to even start, so the skill of the teacher is to match the degree of difficulty of the task to the students in their class. 'Too easy' and there is no satisfaction in solving puzzles, 'too hard' and students will soon give up and feel negative emotions around failure and their lack of ability.

The need to provide appropriate tasks and problems was also recognised by Sawyer (2006), who argued that students today required a deep learning approach in schools, rather than the traditional knowledge transmission approach. His ideas came from the field of Learning Sciences and indicated that this deep learning would be more engaging for students. Again, many of the strategies Sawyer described as successful were the ones recommended for teaching NOS, such as evaluating evidence, argumentation and critical reflection. He emphasised that good teachers must provide

scaffolding to enable students to understand and assimilate new knowledge for themselves. These findings were supported by Silvia (2008), who suggested that people became interested or engaged with situations that were new, complex or surprising, especially if they were comprehensible. Again, a skilled teacher is needed to present just the right level of problem to their students so they are interested, or engaged, but do not become discouraged. Silvia described interest as a knowledge emotion, one that encourages learning and is a strong motivator for people to explore new ideas. These findings should offer encouragement to science teachers presenting NOS and other content related concepts through open-ended questions, inquiry or as Kuhn (1962) suggested, by solving puzzles.

Another strategy found to be effective in engaging students, suggested by Willingham, was to use stories in class. He stated “that psychologists sometimes refer to stories as ‘psychologically privileged,’ meaning that they are treated differently in memory than other types of material” (Willingham, 2009, p. 66). Britton, Graesser, Glynn, Hamilton, and Penland (1983) had previously investigated this idea, and found that when students read material as narratives, they used more of their cognitive capacity than when they read factual, expository material. Britton et al. theorised that people engaged more cognitive capacity when reading material in narrative form, as more meaning was made with the new information. Connections were made with existing memories, images and prior understandings and these increased cognitive engagement. A study that applied these ideas to learning in science (Spiegel, McQuillan, Halpin, Matuk, & Diamond, 2013), found that using comics with a storyline to learn information about viruses increased student engagement, especially for those with low initial interest in science. Thus, using stories to engage students seems to have validity and supports the strategy of teaching NOS through the use of examples and stories, such as from the history of science (Allchin, 1997; Solomon et al., 1992).

In a review of the literature on engagement, Reschly and Christenson (2012) discussed the areas of consensus and disagreement that existed in the research community. There seemed to be general agreement that engagement was a multidimensional construct, but while some included behavioural, emotional and cognitive factors, others added an academic dimension, or identified disengagement

as a construct to be measured separately. However, there was argument about the relationship between motivation and engagement, with some using the terms interchangeably. Reschly and Christenson contended that motivation was an internal process that helped drive engagement. However, they acknowledged that for the practicing teacher these distinctions may not matter. As with NOS research, the key finding for the classroom teacher was that there are strategies that that can be used to influence student motivation and engagement.

Other authors too, have summarised researched based findings on effective strategies for teachers to use to improve engagement. Skinner and Pitzer (2012) explained factors affecting engagement in terms of a model of basic human needs consisting of three parts: the need for relatedness, competency and autonomy. They provided considerable evidence to show that caring, supportive teachers promoted relatedness, while giving students choices and making the work relevant to them, enhanced feelings of autonomy. Scaffolding tasks that enabled students to actively reflect on strategies for learning built competence, and teachers using all three aspects gradually developed resilience within students, enabling them to cope with the inevitable set-backs and failures encountered in life.

Empirical evidence that students have a need for deeper learning, relevance and for strong relationships with teachers, came from comments made by students in a large-scale survey of American high schools (Yazzie-Mintz & McCormick, 2012). Students in the survey indicated that activities that were most likely to engage them in class were discussions and debates, followed by group projects. Both these activities promoted relatedness and competence through collaboration that builds understanding. Skinner and Pitzer (2012) therefore encouraged teachers to monitor both the achievement and level of engagement of their students, as fully engaged students were better equipped to face life beyond school, while those who simply achieved good grades had fewer strategies to cope with adversity.

Finally, in an attempt to sum up research on engagement, a useful working definition of engagement was provided by Christenson, Reschly, and Wylie (2012, p. 817):

Student engagement refers to the student's active participation in academic and co-curricular or school-related activities, and commitment to educational goals and learning. Engaged students find learning meaningful, and are invested in their learning and future. It is a multidimensional construct that consists of behavioral (including academic), cognitive, and affective subtypes. Student engagement drives learning; requires energy and effort; is affected by multiple contextual influences; and can be achieved for all learners.

The value of this view is that it is inclusive and practical. It offers a way for teachers to see the multiple ways they might be able to enhance student engagement, outlines the benefits and indicates that teachers should aim to engage all the students in their classes.

In whichever way it is envisaged, engagement is an area teachers can influence through a range of proven strategies (see Appendix J for a selection identified from this literature review). Many of these strategies are the same as recommended for effective teaching of NOS, which should help convince teachers there is value in these approaches and encourage them to adjust their teaching pedagogies accordingly.

### **3.2.2 Measurement of engagement**

Having agreed on the definition and components of engagement, and established that the engagement of students with their learning was a worthwhile goal, research focused on finding sound techniques for measuring the degree of students' engagement. Early attempts to measure student engagement naturally focused on the behaviour of students in classrooms, as this can be directly observed, whereas emotional and cognitive engagement are more difficult to ascertain. The methods used to find out what students were actually doing involved such techniques as recording the total time available each period compared with time actively engaged in learning activities (Prater, 1992).

Researchers such as Stallings (1980), realised that teachers needed more information about which strategies worked to improve performance or engagement, rather than just the total time spent on task. This raised questions about how to determine exactly what students were feeling, thinking or doing, when apparently on task. This more specific information would be vital for both researchers and classroom teachers in order to receive feedback on the strategies used to improve engagement, such as using a NOS approach. As Hattie (2009) stated, effective teaching and learning requires that the goal, for example high engagement, be made visible, then data collected and fed back to both students and teachers on the strategies used to achieve that goal.

One early study attempting to answer these questions was reported by Peterson, Swing, Stark, and Waas (1984), who looked at elementary students covering a unit of work in mathematics. In order to discover what cognitive and affective thoughts the students had while in the class, Peterson et al. used several questionnaires supported by classroom observations and interviews. The research instruments probed not only attitudes towards mathematics, but which specific cognitive strategies were used, and recorded the thoughts and feelings students used to motivate themselves. The authors' conclusions were that student self-reporting, whether through questionnaires or interviews, was a more valid indicator of their cognitive processes than judgements made by those observing. The level of effort required to gather the data in this study was considerable, with a team of academics and research students collecting multiple observations, interviews and surveys over a period of weeks. Clearly this depth of study to measure engagement is not possible for the practicing science teacher, who as with assessment of NOS knowledge (see Section 2.4) needs some simple but reliable tools, to see whether their teaching strategies are influencing the engagement of their students.

Still concerned with the time spent actively involved in lessons, Finn (1989) identified *participation* as a key determinant of student engagement. Several studies were carried out to measure student participation in class by, for example, making observations every ten seconds and assigning student behaviour into categories such as “attending” and “interacting appropriately with teachers” (Finn, 1989, p. 127). Another technique used by Finn was to ask the teachers to rate their students about

various factors, including participation, and this was found to give a satisfactory indication of engagement while being much cheaper and quicker than classroom observations.

The difficulties in measuring engagement were discussed by Newman et al. (1992), who recognised that engagement could only be indirectly gauged from student behaviours. However, they still recommended inferring levels of engagement by observation of students in class, noting aspects such as the time spent on task, the degree of intensity brought to bear, and the enthusiasm expressed. Other indicators suggested by Newman et al. included examination of student outputs, such as the rate of task completion and the quality of work done. However, they cautioned that all of these indicators were open to misinterpretation, as students may simply be cooperating with the teacher rather than truly engaging with the material. The problems associated with trying to understand exactly what students were doing and thinking were revealed in a series of detailed studies by Nuthall (2002, p.11): “We found that even live observers keeping continuous written records of the behaviours of individual students missed up to 40 percent of what was recorded on the students’ individual microphones.” Nuthall was surprised by how little teachers actually knew about what was going on in their classrooms, so clearly discovering the level and type of engagement of students presents a significant challenge.

Many attempts have been made to overcome these difficulties, and Fredericks et al. (2004) described the various methods used to measure engagement in all three of the dimensions of engagement; behavioural, emotional and cognitive. Behavioural engagement had been approached from several different angles. The direct approach involved surveys of students and teachers, asking questions about the level of student participation, or what the student was thinking about during a particular activity. A different approach came from observing students in class, but Fredericks et al. again noted the problem of determining whether students were on task simply by watching them.

Emotional engagement was found to be measured by a variety of self-response questionnaires with items, for example, asking about the students’ feelings and relationships with their teachers. Fredericks et al. (2004) mentioned several problems

with these surveys, including the difficulty separating emotional and behavioural characteristics, and the confusion regarding both the source and intensity of particular emotions.

Finally, cognitive engagement was rated as the hardest dimension to measure. Student self-report surveys had been used along with classroom observations, again with the major problem identified as truly determining what a student was thinking about and with what intensity. One measure used in observations was to assess the quality and quantity of questions and answers provided by students, which gave an indication of the degree of cognitive engagement taking place. Overall Fredericks et al. concluded that there were still significant problems with measuring engagement.

In order to more accurately gauge the links between specific activities and engagement in learning, an instrument was developed at the University of Missouri, called the Instructional Practices Inventory (IPI) (Valentine, 2005). School-wide classroom observations were made by trained observers using the rubric shown in Table 3.1, which according to Fredericks et al. (2011) included criteria related primarily to signs of cognitive engagement. Further data was collected on student achievement and compared with results from the IPI, revealing significant differences between successful and unsuccessful middle schools

High performing schools in the district had 29.3 per cent of the observations in the “Student Active Engaged Learning” category, compared to only 16.0 per cent for unsuccessful schools (Valentine, 2005, p. 12). The conclusion was that if teachers and schools introduced strategies to improve the cognitive engagement of their students then subsequent improvements in academic achievement would follow.

In a summary of twenty-one instruments for measuring engagement, including the IPI, the difficulties of using the information and comparing results were again stressed by Fredericks et al. (2011, p. i): “... instruments for measuring engagement are not easily accessible as a group in a way that allows for comparison because they arise from different disciplinary perspectives and theoretical frameworks.”

Table 3.1

*Instructional Practices Inventory (IPI) categories, Valentine (2005).*

<b>Broad Categories</b>	<b>Coding Categories</b>	<b>Common Observer “Look-fors”</b>
<b>Student Engaged Instruction</b>	<i>Student Active Engaged Learning</i>	Students are engaged in higher-order learning. Common examples include authentic project work, cooperative learning, hands-on learning, problem-based learning,
	<i>Student Learning Conversations</i>	Students are engaged in active conversations that construct knowledge. Conversations may have been teacher stimulated but are not teacher dominated. Higher-order thinking is evident.
	<i>Teacher-Led Instruction</i>	Students are attentive to teacher-led learning experiences such as lecture, question and answer, teacher giving directions, and video instruction with teacher interaction. Discussion may occur, but instruction and ideas come primarily from the
<b>Teacher-Directed Instruction</b>	<i>Student Work with Teacher Engaged</i>	Students are doing seatwork, working on worksheets, book work, tests, video with teacher viewing the video with the students, etc. Teacher assistance or support is evident.
<b>Disengagement</b>	<i>Student Work with Teacher not Engaged</i>	Students are doing seatwork, working on worksheets, book work, tests, video without teacher support, etc. Teacher assistance or support is not evident.
	<i>Complete Disengagement</i>	Students are not engaged in learning directly related to the curriculum.

Some measured behavioural, emotional and cognitive engagement, while others only one or two of these dimensions. The focus of the instruments also varied

considerably, for example targeting engagement with school, in class, or with academic learning. Some were designed for students to self-report on their engagement while others, were for teacher reports or classroom observations. A further distinction was between those designed for elementary school and those for high school.

Further analysis of the advantages and limitations of a variety of approaches to measuring engagement was conducted by Fredericks and McColskey (2012). They recommended student self-report surveys as being particularly useful for measuring emotional and cognitive engagement, as these aspects of engagement were not directly observable. An advantage of self-report surveys was that they were cheap and quick to administer, so they could be used for large samples and repeated easily in longitudinal studies. Teacher ratings of students was deemed to be effective in measuring behavioural engagement, as teachers were skilled in recognising these in class. Interviews and observations were excellent for providing the rich descriptions required to understand the complex and contextual factors around student engagement. Cognitive engagement could, for example, be reliably inferred by the analysis of classroom discourse, noting the quality of questions students asked, and how students assimilated the current task with prior knowledge.

A different view on self-reported measures of engagement was presented by Olitsky and Milne (2012), who suggested that these were of little use to teachers for guiding change in practice, because the level of engagement was so variable and context dependent. They gave more weight to classroom observations that examined behaviour of students to reveal the overall level of engagement, especially if carried out over a period of time. By examining video recordings or transcripts of lessons, patterns of engagement could be discerned which revealed the importance of social interactions in the classroom context. Using this information, a teacher could see how to structure the class to promote more participation and engagement. Olitsky and Milne described some types of behaviour in science classrooms that could be used to infer cognitive engagement, including use of scientific language, a willingness to ask questions and to seek explanations for observations.

In another critique of methods to measure engagement, one of the fundamental difficulties when tackling psychological constructs such as engagement was pointed out by Samuelsen (2012, p. 805): “The correlation between what we set out to measure and what we end up measuring is limited by the quality of our definition of that construct”. Given the multidimensional nature of engagement described by most researchers, and the complex interactions between these dimensions, Samuelsen described engagement as being challenging to measure.

Some of the other problems with item response instruments were also identified by Samuelsen (2012), such as: appropriate reading level; the tendency of people to answer in the way they think most people would; and the question of how many choices to give in Likert-like scales. However, as Fredericks and McColskey (2012) concluded, research into student engagement was such a promising field for making improvements in learning that it was worth the effort to create valid and reliable instruments to measure engagement, despite the difficulties identified. They recommended mixed methods approaches which combined student surveys, interviews and classroom observations, as the best way of capturing the complex interactions that contributed to student engagement in the classroom. This has been the approach taken in the current research, with the methodology fully described in Chapter 4.

### **3.2.3 Attitudes towards science and engagement**

As part of the mixed method research design used in this project, a survey was carried out to determine students’ attitudes towards science using the Test of Science-Related Attitudes (TOSRA) instrument, produced by Fraser (1978a). Therefore it was appropriate to review the literature concerning instruments for measuring student attitudes, and investigate the links between attitudes and engagement. Firstly, however, it is necessary to distinguish between different sorts of attitudes in science. Cultivating both scientific attitudes and positive attitudes towards science has long been a goal of curriculum designers and science educators (Bolsted & Hipkins, 2008; Dewey, 1935; Solomon, 1991). Scientific attitudes are closely aligned with NOS, and include such characteristics as open-mindedness, scepticism and integrity (Davis, 1935). Attitudes *towards* science, however,

encompass a wide range of factors to which a student might express a positive or negative opinion, for example, towards school science, science as a career, scientists, or even the role of science in society.

In an early review of attitudes towards science Gardner (1975, p. 2), defined these attitudes as “the emotional reactions of students towards science”, in other words, emotional engagement with science. Gardner criticised many of the studies and research instruments used to investigate student attitudes towards science. He claimed that some did not clearly define the attitude being measured, while others combined several different attitude constructs into a single, essentially meaningless score.

The TOSRA was developed by Fraser (1978a) to investigate students’ attitudes to science, and to address the issues of validity and reliability raised by Gardner. It was designed to measure seven distinctly different attitudinal aspects, each requiring student responses to a set of ten items. These are listed in Table 3.2, along with a sample item for each, and an indication of how they could be interpreted from the perspective of engagement with science. Items were constructed using simple language appropriate to junior high school students, with students required to agree or disagree with each item on a five point Likert scale. To address concerns expressed by Gardner (1975), the TOSRA was extensively field tested, with over one thousand students from a wide range of schools, producing results showing both good internal consistency and test-retest reliability. Fraser (1981) also specifically stated that the scores should not be combined into single number, addressing Gardner’s criticism that it is meaningless to combine scores from unrelated constructs.

The TOSRA has since been used in many research studies with high ratings in reviews of attitude instruments by Blalock et al. (2008), with Haladyna and Shaughnessy (1982, p. 549) stating, “the Test of Science-Related Attitudes, has a sound theoretical basis and an impressive empirical validation”. One of the factors contributing to the reliability and validity of the TOSRA has been its use in multiple studies, enabling comparisons of accumulated data. Blalock et al. (2008) noted that the majority of attitude researchers created their own instruments and these were

Table 3.2

*The seven TOSRA scales and their relationship to student engagement.*

<b>TOSRA Scale</b>	<b>Sample item</b>	<b>Link to Engagement</b>
<b>Social implications of science</b>	Science can help to make the world a better place in the future	Emotional and cognitive – feelings and thoughts towards science in general
<b>Normality of scientists</b>	Scientists can have a normal family life	Emotional – scientists are people with feelings
<b>Attitude towards scientific inquiry</b>	I would rather solve a problem by doing an experiment than be told the answer.	Cognitive – use of higher level thinking skills and metacognition required in problem solving
<b>Adoption of scientific attitudes</b>	I enjoy reading about things which disagree with my previous ideas	Emotional and cognitive – satisfaction gained from conceptual change which results in useful and fruitful ideas
<b>Enjoyment of science lessons</b>	I really enjoy going to science lessons.	Behavioural and emotional – positive feelings lead to increased participation in class
<b>Leisure interest in science</b>	Talking to friends about science after school would be boring	Behavioural and emotional – positive feelings lead to increased participation beyond school
<b>Career interest in science</b>	A job as a scientist would be interesting.	Behavioural, emotional and cognitive – all three elements are needed if students are to commit to a career as a scientist

generally used only once, while nearly half of those critiqued had some aspect of psychometric evidence missing. Blalock et al. recommended that researchers use the best existing instruments so that useful comparisons and generalisations could be made, based on reliable and valid results. A more recent review (Bennett, Braund, & Sharpe, 2013) on research into attitudes and engagement in science supported these points, noting the difficulty of summarising research from many different countries and contexts, using many different research instruments.

An example of research which investigated the more specific link between attitudes towards science and emotional engagement with science, was a study by Germann (1988), who developed and tested an instrument called the Attitude Toward Science in School Assessment (ATSSA), and used this to look for any link between attitude and achievement. This instrument focussed only on the feelings of students towards school science in general. It used a fourteen item Likert-type questionnaire which included statements such as, “I feel at ease with science and I like it very much”, and “Science makes me feel uncomfortable restless, irritable, and impatient” (Germann, 1988, p. 701), to determine students’ emotional response towards science. Germann constructed the instrument to assess the impact of a student’s feelings towards science on their achievement in science. He found that students with a positive emotional attitude had higher achievement scores for internal assessments.

The direct relationship between attitudes towards science and engagement was also investigated by Ebenezer and Zoller (1993). They studied the attitudes of junior high school students in Canada towards science using both quantitative (survey questionnaire) and qualitative (interviews) techniques. They noted several factors which students identified as enjoyable or engaging. These included: doing experiments or investigations with some element of student direction; studying science-related issues of local significance; and making science relevant to their own lives. Ebenezer and Zoller (1993, p. 184) concluded, “In being responsible for their own knowledge construction, students are mentally and emotionally engaged with what they are learning”. Conversely, excessive note taking, answering questions from the text book, and rote learning of facts as opposed to understanding concepts, were regarded as disengaging. The authors commented that although the quantitative data gave them a broad overview of students’ attitudes, it was the interviews that

really allowed them to understand why the students held particular attitudes towards science.

In a review of the literature on attitudes towards science, Osborne et al. (2003b) agreed with previous suggestions that attitude is an affective construct primarily concerned with students' feelings. Osborne et al. noted a wide range of techniques to describe or measure student attitudes, which reflected the difficulty of obtaining reliable results. The most common methods used attitude scales such as the TOSRA and ATSSA previously described, which they cautioned must be interpreted carefully. Other methods noted were: surveying students regarding the subjects they liked; collecting data on actual subject choices made; and using interviews to discover the reasons behind the attitudes expressed. The accumulated data seemed to indicate that attitudes towards school science declined as students moved through secondary school, but that attitudes to science in general remained positive. Another finding was that classroom environment and the quality of teaching were major influences on student attitudes towards science. The factors that had a positive effect of students' attitudes were similar to the ones identified as increasing engagement, as noted in Appendix J, including: creating a supportive learning environment and allowing students input into their own learning goals. Osborne et al. (2003b) concluded that research had been useful in revealing problems due to poor attitudes towards school science, but that the emphasis should now shift to more research into students' underlying motivation, and the production of strategies that improved engagement with science in schools.

One international project with the aim of using student attitude information to improve engagement in school science was the Relevance of Science Education (ROSE) Project. The section concerning attitudes towards school science had sixteen items with students required to agree or disagree on a four step Likert-like scale. These items included references to emotional engagement such as; "I like school science better than most other subjects", and to cognitive engagement; "School science has made me more critical and sceptical" (Jenkins & Nelson, 2005, p. 45). No attempt was made to combine items into an overall attitude rating, individual items being analysed or compared with other factors in the survey. In England analysis of the ROSE data led Jenkins and Pell (2006) to conclude that although the

majority of fifteen year olds saw science as important, they did not make the same connection with school science. They also commented that most students of this age had already made up their minds concerning their career path. Jenkins and Pell recommended that efforts be made to engage students with school science at a younger age so that they see the possibility of themselves continuing in science. These findings suggest that it would be worthwhile investigating whether a NOS approach can increase the engagement of Year 9 students, as they are mostly thirteen years old.

The close relationship between attitudes and engagement was also discussed by Reid (2011), who described attitudes towards any object or concept, such as science, as being stored in the brain's long-term memory and consisting of three parts: a knowledge or cognitive component; an affective component of feelings towards the object; and a behavioural component, the way a person behaves as a result of their attitudes. These connections between attitudes and engagement bear a remarkable similarity to the components of engagement itself, as defined by Fredericks et al. (2004). Reid's summary of research on attitudes to science indicated that teachers had a major influence on the attitudes of their students, that making careers in science explicit improved student attitudes, and that the most effective interventions to improve attitudes took place in primary and junior secondary school.

The difficulties in measuring attitudes were also acknowledged by Reid, but he supported the use of surveys, and made some recommendations to ensure their validity and reliability. First, the items used should be checked by people who knew the students and were familiar with attitude research to ensure the language was suitable. Second, sample sizes should be as large as possible, preferably over two hundred, and there should be questions that test the same idea, but expressed in different ways. Third, a sample of students should be interviewed afterwards to check if their views were the same as the ones recorded in the survey, and to look for reasons for these views. Finally, responses to items should be examined individually, rather than being added together in scales, as it was impossible to determine the true weighting of each item for a particular attitude, and different item responses often cancelled each other out. Reid argued that this final point was one of the reasons why many studies on attitudes to science found little change following specific

interventions. He recommended looking at individual items backed up by interviews to reveal the fine detail needed for teachers to be able to determine what makes a difference in improving attitudes towards science.

Support for quantitative studies in research on attitudes towards science was provided by Kind and Barmby (2011), who argued that they were an efficient way of collecting data, but that the criticisms of Likert scales by several researchers (Blalock et al., 2008; Gardner, 1995; Lederman 2007) could be addressed. The key requirements were for careful construction of the scale and elimination of any items within a particular scale that did not support the initial construct. Kind and Barmby described how one of the scales in their earlier attitude towards science questionnaire (Kind, Jones & Barmby, 2007) was adjusted following Rasch analysis of the data for all items. They found that the items “Scientists have exciting jobs”, and “There are many exciting things happening in science and technology”, were more difficult for students to endorse than the other items, in the importance of science scale, so these items were subsequently removed. They attributed the problems with these items as due to their more emotional content when compared to other items originally in the scale such as, “Science and technology is important for society”. In a subsequent study Barmby et al. (2008), found the new scales were extremely accurate and reliable, the results showing fine and explainable differences between the attitudes of girls and boys in pre- and post-tests, following specific interventions.

Finally, the survey with the most data concerning attitudes towards science worldwide is the Trends in International Mathematics and Science Study (TIMSS). Run every four years since 1994, with forty-five countries participating in the junior secondary survey in 2010/11, the survey measures student achievement and attitudes, as well as the perceptions of teachers and aspects of the school environment. Attitudes are measured using a twenty-three item Likert-response questionnaire consisting of three subscales; Students Like Learning Science scale (SLS), Students Value Science (SVS), Students Confident in Science (SCS). The results for New Zealand were analysed by Caygill, Kirkham, and Marshall (2013), who found that the proportion of Year 9 students agreeing that they enjoy science has been steady at around 71 per cent since 1994, and that those who were more positive about science had higher achievement scores. However, Caygill et al. (2013, p. 6) stated,

“Compared to other countries, on average, fewer New Zealand Year 9 students liked science, were confident in their ability to do science, and valued science”. The main factor identified by teachers as limiting their ability to teach science was having disruptive or uninterested students. These results indicated that improvements are needed to engage students and to increase their self-efficacy in science, which should lift both their understanding and academic performance. Again, these findings provide a strong rationale for investigating whether teaching with a NOS approach does engage students in science classes.

### **3.2.4 Research specific to engagement in science**

Over thirty years ago, Capie and Tobin (1981) noted that there were very few studies related to school science and engagement. They recommended that more work be done in this area as they felt it had the potential to make a significant difference for the practicing science teacher. The literature they did find showed positive links between time spent on productive learning in class, and student achievement. The studies they examined revealed some common characteristics of lessons that engaged students, many of which are similar to the approaches seen to be successful for teaching NOS. Students were more likely to be engaged in classrooms where there were plenty of opportunities to participate, particularly in discussions where there was useful feedback. Working constructively in groups was also seen as beneficial for students, along with establishing positive relationships with the teacher and with other students. All these factors link to the collaborative NOS, and the importance of explicit reflection and discussion, which as Capie and Tobin pointed out, are factors able to be directly influenced by the teacher.

One model of science instruction that recognised the need for engagement was developed in America by the Biological Science Curriculum Study (BSCS) in the 1980s. It consisted of five steps for teachers to use in class to promote conceptual change in science, called the 5Es; engagement, exploration, explanation, elaboration and evaluation. In a paper arguing that the 5E method was still relevant today, and a good way of teaching twenty-first century thinking skills, Bybee (2009) described how this approach had been extremely successful and widely used in America. He suggested that the crucial first step of engaging students should be set up by teachers

using “activities that promote curiosity and elicit prior knowledge” (Bybee, 2009, p. 5). In an earlier major review of the research in this area, Bybee et al. (2006) found that using the learning cycle and 5E instructional approach not only improved students’ attitudes towards science, but students enjoyed science more, had better motivation and were more likely to complete their courses. These results indicated that behavioural, cognitive and emotional engagement could be improved through consistent use of the 5E teaching strategy.

A major report commissioned by the Australian government (Tytler et al., 2008), looked explicitly at the factors that might improve engagement of school students with STEM subjects. Their findings concerning teacher pedagogy were similar to those previously reported, that is, the use of collaborative, inquiry-based work that is relevant to students does increase engagement. However, Tytler et al. also summarised research on the values and attitudes of students that were significant in determining subject choice and future engagement with science. They found that students wanted careers that had meaning for them, and wanted to make a personal contribution to the future. The authors concluded that the traditional delivery and philosophy of science in school did not match these aspirations, and went so far as to suggest, “what is needed is a transformation of the vision offered by school science – in essence a cultural and societal transformation that recognises the value of science and explains why science matters” (Tytler et al., 2008, p. 85).

An alternative view of student agency and engagement was provided by DeWitt et al. (2013), who interviewed the peers and parents of a set of ten-year-old children, who were identified as highly engaged with science. The researchers asked both groups about their views of children and scientists who were obviously ‘into’ science. They found that the participants had generally positive views, regarding those engaged with science as hard-working, clever, and highly focused. DeWitt et al. concluded that one way of encouraging more students into choosing science, was to broaden their appreciation of science-related careers and the diverse range of people working in these fields.

This view was supported by Bolstad and Hipkins (2008), who suggested that students need to see the possibility of themselves in science, or as scientists in the future, in

order to engage with science in the present. This is another aspect mentioned as a justification for teaching NOS – giving students an understanding of how current scientists actually work (Freire et al., 2013; Tytler et al., 2008) – and was also the rationale for setting up The Science Learning Hub (SLH) in New Zealand (Science Learning Hub, n.d.). This online resource provides teachers with many examples of scientists working in a wide range of contexts. Chen and Cowie (2014) reported that teachers and students in New Zealand were engaged through use of the SLH video clips, as they were perceived as locally relevant and provided authenticity. Engagement also came from students viewing scientists making a difference in the community, tackling issues such as high ultra-violet radiation and pollution, thus appealing to students' desire to make a difference in the future.

Finally, considering work on engagement with school science, Olitsky and Milne (2012, p. 31), argued “it is the collective emotional experience that leads to individual student confidence, thereby making cognitive engagement possible”. These findings were based on detailed observations in high school chemistry classes in Philadelphia (Milne & Otiento, 2007; Olitsky, 2007), where individuals became engaged once they felt emotionally enabled through a supportive and accepting class culture. Olitsky and Milne (2012) suggested that teachers could foster this culture by asking open-ended questions and valuing the students' responses. Once these conditions were established, students were willing to tackle harder problems, such as chemical equation balancing, where they clearly enjoyed the emotional rewards that came with deeper cognitive engagement.

### **3.2.5 Summary of engagement and NOS**

Research on engagement has developed considerably over the last thirty years. There are now sophisticated theories to explain how and why students become engaged with their learning and general agreement on the crucial importance of engaging students in school (Fredericks et al., 2004; Reschly & Christenson, 2012). Breaking down the overall concept of engagement into behavioural, emotional and cognitive engagement dimensions has been useful for teachers and researchers alike, in order to develop appropriate strategies to target each one. There is considerable support for creating a learning environment that encourages emotional engagement as a first

step (Cornelius-White, 2007; Olitsky & Milne, 2012), as once students feel emotionally connected to the class, teacher or task, they are likely to become behaviourally and cognitively engaged.

One conclusion which is significant for the current research, is that many of the strategies shown to improve student engagement are very similar to those shown to improve NOS understanding, as illustrated in Appendix K. If teachers can be convinced that using these strategies improves both NOS understanding and engagement of students, they might be more willing to try them in their classrooms. This should lead to an improvement in teachers' working conditions as they create classrooms with more engaged and positive students, and produce students with the confidence and competencies to meet the challenges of the 21<sup>st</sup> century.

### **3.3 Science curriculum implementation, NOS and engagement**

#### **3.3.1 Introduction**

In an analysis of curriculum change around the world, Fensham (1994), noted a common feature of many new curricula was the inclusion of NOS. A measure of the global nature of this trend can also be seen in the research literature concerning NOS. In a review of over one hundred publications concerning implementation of NOS, Deng et al. (2011) cite studies from over twenty countries, representing every continent. McComas and Olson (2002) analysed NOS as described in the science curricula of five English speaking countries, and found considerable agreement between them regarding the NOS concepts included, with for example, the tentative nature of science noted in all of them. Clearly, the inclusion of NOS into science curricula is happening around the world.

The first part of this review examines science curriculum development in four countries to investigate how and why NOS has been incorporated in curriculum documents, especially in relation to the engagement of students. Section 3.2.6 then examines the difficulties of implementing curriculum change in science due to competing objectives, and finally Section 3.2.7 focuses on what actually happens in the classroom as a result of the intended curriculum.

### 3.3.2 The science curriculum in New Zealand

In New Zealand, the first attempt to introduce NOS came in the 1990s with the release of *Science in the New Zealand Curriculum* (Ministry of Education, 1993). This document was an attempt to introduce many of the recommendations coming out of science education research into a coherent curriculum across all levels of schooling, from junior primary to senior secondary. There were twelve specific aims for science education, including: science skills; attitudes and processes; and exploring issues. NOS was specifically included as part of two major strands which teachers were supposed to weave through the content, called *understanding of the nature of science and technology* and *developing science skills and attitudes*.

As a full-time teacher at the time of this curriculum implementation, I remember many of the issues that teachers faced, and the considerable work we did in adapting the national curriculum for use in the school's science department. I was deeply shocked when preparing this thesis to find that NOS was actually mentioned in the 1993 curriculum document, as I had no memory of its inclusion. Hipkins (2012) reported that this feeling was widespread, and found that there was very little evidence of NOS being taught in science lessons as a result of the 1993 curriculum.

The reasons for these problems in implementing the curriculum were analysed in two reports commissioned by the Ministry of Education to review the overall curriculum implementation (McGee et al., 2003b, McGee et al., 2004). One key finding was that a large majority of science teachers did not feel there was enough guidance in the curriculum documents to enable them to deliver the two integrating strands. Other factors identified as problems included: too much content to deliver; too little time and support to prepare resources; and confusion about the inclusion of technology in the NOS strand.

As a result of these reports on the 1993 curriculum, and in response to increasing societal and technological change worldwide, The New Zealand Curriculum (NZC) was developed to be implemented in 2010 (Ministry of Education, 2007a). This document was constructed with 21<sup>st</sup> century learning in mind, as described in Section

1.2. The emphasis on values such as critical thinking and decision making, was clearly articulated, and helped give NOS more weight in the science curriculum.

As recommended by the Australian Council of Educational Research report (McGee et al., 2003a) on the 1993 curriculum, the new science curriculum collapsed the two integrating strands into one, labelling this as NOS. Thus NOS was placed at the heart of the science curriculum, clearly separated from technology, skills or attitudes, and described as “the overarching, unifying strand” (Ministry of Education, 2007a, p. 28), through which the content would be delivered. The thinking behind these changes was well described by Hipkins (2012), the aim being to signal that the purpose of science teaching was to enable students to use science knowledge and processes to make informed decisions in a modern society dependant on science.

Another major report (Hipkins et al., 2002) which had a significant influence on the new curriculum, recognised the importance of teaching pedagogies that engaged students in science. Its authors recommended many of the strategies noted in Appendix K, and shown to be effective at both delivering NOS and engaging students. These recommendations were incorporated into the NZC through an emphasis on NOS in the science curriculum, but even more so in the section on effective pedagogy (Ministry of Education, 2007, p. 34). Here, teachers were directed to use strategies such as creating a supportive learning environment, and making the learning relevant to students. Again, as discussed in Section 3.2.4, these have been shown to be effective strategies for both engaging students and delivering NOS.

Despite the clear intention to make NOS central to the delivery of all science lessons, the detail regarding what should actually be taught was complex and confusing. In the NZC document itself the NOS strand was broken down into four sections with only the first, *Understanding about science*, specifically addressing NOS as commonly described in the literature. The second section, *Investigating in science*, covers Scientific Inquiry, while the final two sections, *Communication in science* and *Participating and contributing*, are more related to the overall intent of the curriculum rather than NOS. More detail concerning each of these sections was given

Table 3.3

*Comparison of NOS achievement aims and objectives from the NZC (Ministry of Education, 2007b) for use in Junior High School, and NOS themes based on the literature reviewed in Chapter 2.*

<b>NOS Achievement aims</b>	<b>Level 5 and 6 NOS objectives</b>	<b>NOS themes</b>
<b>Understanding about science</b>	Understand that scientists' investigations are informed by current scientific theories and aim to collect evidence that will be interpreted through processes of logical argument.	Empirically based Observation v inference Argumentation
<b>Investigating in science</b>	Develop and carry out more complex investigations, including using models. Show an increasing awareness of the complexity of working scientifically, including recognition of multiple variables. Begin to evaluate the suitability of the investigative methods chosen.	Scientific method and critical testing Scientific method and critical testing Scientific method and critical testing
<b>Communicating in science</b>	Use a wider range of science vocabulary, symbols, and conventions. Apply their understandings of science to evaluate both popular and scientific texts (including visual and numerical literacy).	No recognised NOS theme Argumentation
<b>Participating and contributing</b>	Develop an understanding of socioscientific issues by gathering relevant scientific information in order to draw evidence-based conclusions and to take action where appropriate.	Argumentation Socially/culturally embedded

to teachers through a separate curriculum document (Ministry of Education, 2007b), which listed NOS objectives for every year of primary and secondary schooling. A comparison of these objectives with NOS themes from the literature is shown in Table 3.3 for Level 5 and 6 of the curriculum, which would be delivered to students in Year 9 and 10, the first two years of high school in New Zealand.

The table shows that only five of the ten NOS themes identified in the literature were covered, while one of the NZC objectives related to communicating in science has no obvious counterpart in the NOS literature. Although the NZC (Ministry of Education, 2007a) document did mention the tentative NOS and that creativity is required in science, these and other NOS themes did not appear in the specific learning objectives. Thus, teachers had to look through different parts of two separate documents in order to find out what to teach regarding NOS, and even then, only the broadest indicators were given. Hipkins (2012) acknowledged that working out what parts of NOS to teach and exactly how to deliver them was no easy task for teachers, and these difficulties meant that teachers tended to continue with their familiar content-based approach to science teaching, rather than deliver NOS as intended by the new curriculum.

### **3.3.3 The science curriculum in England and Wales**

A national curriculum was first introduced in England and Wales in 1989 with the science component laid out in considerable detail (Department for Education, 1989), through seventeen specific attainment targets set for children aged from five to sixteen. There was no mention of NOS in this document but the first of the attainment targets was called ‘exploration of science’ and required students to learn and apply the methods of scientific inquiry. Developments in the science curriculum were described by Erduran and Wong (2013), who noted there were several revisions with an increasing emphasis on NOS, although still under the heading of scientific inquiry, or later as ‘How Science Works’. For example, in the 1999 update (DfEE/QCA, 1999, p. 28), students at junior high school were expected to learn about: “the ways in which scientists work today and how they worked in the past, including the roles of experimentation, evidence and creative thought in the development of scientific ideas.”

As with the New Zealand science curriculum, these ideas were meant to be woven through different contexts as the content was covered. In a review of the English science curriculum over the previous twenty years, Millar (2011) argued that the inquiry attainment target produced a rigid, routine approach to practical science in schools, rather than the more open, genuine reflection of NOS that was intended. Another criticism of the curriculum was that it contained far too much content (House of Commons Children, Schools and Families Committee (HCCSFC), 2009) and although this had been reduced through successive revisions (Oates, 2009), teachers were still struggling to achieve all the attainment targets. This content load and prescribed curriculum lead to lessons that were “dependent on a recipe handed-down by Government rather than the exercise of professional expertise by teachers” (HCCSFC, 2009, p.4), a situation hardly conducive to delivery of NOS. Osborne (2007) too, recognised the problems generated by the rigid content-based curriculum and saw this type of curriculum as incompatible with the flexible requirements of 21<sup>st</sup> century learners. He recommended that if scientific literacy and NOS were to be genuinely delivered in the classroom, then not only did the science curriculum need transformation, but so did teaching pedagogy.

The result of these criticisms and reviews was the publication of a new science curriculum for England and Wales (Department for Education, 2013), which had three key aims: first, content knowledge in biology, chemistry and physics; second, the nature and processes of science including inquiry; and finally, the implication and use of science. NOS was included in the second of these aims and was broadly described as ‘working scientifically’, with teachers again expected to weave these ideas through all of the content delivered. However, there was still considerable emphasis on content knowledge especially for late primary and junior high school teachers, as illustrated by this directive to primary teachers in the science curriculum (Department for Education, 2013, p. 2): “The principal focus of science teaching in key stage 3 is to develop a deeper understanding of a range of scientific ideas in the subject disciplines of biology, chemistry and physics.”

This view was emphasised by the chair of the Expert Subject Advisory Group for science Hoyle (2013), who clearly stated that the content in the new science

curriculum was more demanding, and that teachers, especially at primary level, would require professional development to update their own content knowledge. Thus it would seem that despite the increased emphasis on NOS and applications of science in the curriculum, teachers were still getting strong messages about the importance of traditional content knowledge.

Concern that the curriculum reforms in the United Kingdom (UK) had not produced the desired outcomes of increased engagement and participation in science, prompted the Royal Society to commission a widespread review of science and mathematics education in the UK (The Royal Society, 2014). As a result of the review, a clear vision for science education was produced. A key recommendation was that school science should be focussed around experiments and problem solving, with the aim of developing the ability of students to think scientifically. The components of scientific thinking described in the review included many well recognised NOS themes such as: an understanding of scientific methods and critical testing; the tentative NOS; and the requirement for evidence-based argumentation. The review also recognised the importance of putting more time and resources into professional development opportunities for teachers so that they had the skills and knowledge to inspire students. Thus, as with curriculum change in New Zealand, it would appear that simply including NOS in the curriculum had not changed teacher practice, and much more support for teachers was needed to enable teachers to deliver NOS in their classrooms. However, NOS was still seen as an effective way to increase the engagement of students with science.

### **3.3.4 The science curriculum in Australia**

A new national curriculum for science was introduced in Australia in 2010. The overall rationale for the new curriculum was explained in the Melbourne Declaration on Educational Goals for Young Australians (MCEETYA, 2008) which identified a need for change in order to prepare students for life in the 21<sup>st</sup> century. The key goals were to promote excellence and equity, and produce creative and informed citizens who were able to think logically and solve problems. These broad curriculum aims clearly support NOS ideas, and were deeply embedded into the science curriculum. Another interesting feature was the recognition that there were different objectives

for the curriculum at different year levels, with the middle school years acknowledged as “a time when students are at the greatest risk of disengagement”, and that “student motivation and engagement in these years is critical” (MCEETYA, 2008, p. 12).

These ideas encouraging teachers to deliver content in contexts that engaged students were made even more explicit in *The Shape of the Australian Curriculum* (ACARA, 2013), a document designed to explain to teachers and the wider education community the rationale and intent of the new curriculum. The need for students to understand content knowledge, and to know how it has developed and how to use it, were again emphasised, and supported similar NOS ideas that appeared in the science curriculum. The national curriculum also outlined seven general strands which were to be included in all subjects, one of which was called *critical and creative thinking* (ACARA, 2015). The key ideas in this strand are illustrated in Figure 3.2, and were developed further in the science curriculum, specifically instructing teachers to apply these ideas to scientific inquiry.



*Figure 3.2*

Organising elements for critical and creative thinking (ACARA, 2015).

Thus, the NOS themes requiring the understanding of scientific methods and critical testing, along with creativity and imagination, were clearly seen as important for the effective delivery of the new curriculum.

The science section of the Australian curriculum began by outlining the rationale for teaching science, concluding that (ACARA, 2015, science learning area rationale): “The ability to think and act in scientific ways helps build the broader suite of capabilities in students as confident, self-motivated and active members of our society.” This statement clearly links NOS to the engagement of students, as thinking scientifically requires an understanding of NOS (The Royal Society, 2014), and being a capable, confident person equates to being competent, a key factor identified as crucial to the engagement of students (Newman, 1992).

The seven aims of the science curriculum were then specified, emphasising: the need to stimulate interest; to promote the importance of science and its methods to solve problems; and to include the role science plays in deciding social and ethical issues. Only the final aim was concerned with the traditional content of science, organised under the headings, biology, chemistry, physics and earth science. In the matrix of learning objectives subsequently provided for each year of schooling, science was divided into three strands called: Science Understanding (traditional content knowledge); Science as a Human Endeavour (SHE); and Science Inquiry Skills (SIS). The SHE strand contained a sub-strand called the nature and development of science, which is where many NOS themes were identified, although some of these were also evident in the SIS stand, where, for example, evaluation of scientific claims, or argumentation was required. Teachers were directed to incorporate all three strands in their lessons.

Despite the clear directive to integrate the strands when teaching science, Fensham (2016), criticised the new Australian science curriculum as being too disciplinary based, with the Science Understanding strand still being focussed on traditional content knowledge. One reason Fensham suggested for this, was the continuing demand for accountability which can be more easily satisfied by nationally administered examinations in the familiar high status disciplines such as physics and chemistry. Venville, Rennie and Wallace (2012) noted that the more integrated a

curriculum, the less status it was accorded, whereas those based on the traditional disciplines of science were perceived as having more value. This was seen as an impediment to curriculum reforms such as requiring teachers to integrate NOS or SHE with traditional content knowledge.

Another impediment to the implementation of a curriculum which required the integration of NOS with content knowledge, identified by Fensham (2016), was the considerable support that science teachers would require to change their pedagogy. In an analysis of the implementation of the new science curriculum in Queensland primary schools, Lowe and Appleton (2015) noted these same factors as being problematic. That is, the teachers had insufficient time, resources or expert support to make any meaningful change to their pedagogy, concluding that despite the best of intentions on the part of the teachers, little had changed concerning the delivery of NOS in the classroom.

### **3.3.5 The science curriculum in the United States of America**

The history of science curriculum changes in the United States was well summarised by DeBoer (2014), who identified several major changes in focus over more than 100 years of public education. These included: an initial emphasis on the rote learning of science facts; a change to science based on observation and discovery; and a more progressive outlook for science based on personal growth and relevance to the students. DeBoer described the change to a standards-based system in the 1990s as an attempt to bring more rigour and accountability back to all subjects, a response to perceived failings in the economy. In science, this meant the development of standards at every school level which clearly stated what students were expected to know. Each State was then expected to formulate its own curriculum, teaching and assessment programme based on these national standards. Despite all these changes, DeBoer argued that the overall purpose of science education remained surprisingly clear – a commitment to teaching both the content of science and NOS so that students could think logically and use the content knowledge productively.

The most recent development in the United States has been the release of The Next Generation Science Standards (NGSS) in 2013 (NGSS Lead States, 2013). Although

not described as a national curriculum, the Standards contained more detailed direction for teachers than many curricula in other countries. The rationale given for creating yet another set of science standards was to address several major problems again facing the American economy and society. These included the loss of its competitive edge and poor performances by students in science when compared with other countries. Allied to this was a recognition of the increased importance of several years of science education for students to secure good jobs, and the need for improved scientific literacy in the general population in order to make sound evidence-based decisions. The aims of the new standards were further explored and explained in *A Framework for K-12 Science Education* (NRC, 2012), which claimed that the current standards did “not provide students with engaging opportunities to experience how science is actually done” (p. 1). This was a clear directive that teachers needed to include NOS and make their lessons engaging.

NOS was included in both *scientific and engineering practices* and *crosscutting concepts*, two of the three key dimensions that make up the NGSS. The other dimension called *disciplinary core ideas*, consisted of traditional content knowledge. The Framework made it clear that the intent was to reduce content, allowing time for more in-depth exploration of the core ideas and build understanding of the processes and practices of science and engineering. Osborne (2014b) offered an explanation for the change from science as inquiry to science as a set of practices in the NGSS. He argued that this terminology more accurately reflected how science is carried out, and placed the NOS themes of argumentation and critical testing at the heart of these practices. However, as Lederman and Lederman (2014) pointed out, the intent of the Framework was not so clearly espoused in the NGSS, which gave more emphasis to the more concrete science practices, rather than to reflection about NOS and understanding how and why science works. Lederman and Lederman strongly argued that as the stated goal was to create a scientifically literate population, then these cognitive and critical aspects of NOS must also be emphasised.

An in-depth analysis of the NGSS was published by McComas and Nouri (2016) who compared a list of twelve key aspects of NOS, as recommended in the literature, with the NOS aspects included in the NGSS. They concluded that although it was a step forward to have NOS valued and included in these national standards, the other

three themes had greater prominence, and teachers would only appreciate the importance of NOS if they read two additional documents. Furthermore, some aspects of NOS, such as the difference between observation and inference, were missing, while reference to the importance of creativity in science would be very hard for teachers to find. Thus, although the intentions of the NGSS writers seemed sound regarding NOS, as with the New Zealand curriculum, the final product did not make it clear to teachers exactly what constituted NOS, or how and when to teach each of the key NOS themes.

### **3.3.6 Competing objectives in science curricula**

The review of science curricula in the previous sections raises the issue of competing objectives for science education in schools. Gluckman (2011) discussed these competing objectives in a report examining the purposes of science education in New Zealand. He identified two distinct objectives which he described as *pre-professional* and *citizen-focused*. The first of these is to provide students with the content knowledge and skills needed to progress onto tertiary education and science-related careers. The second requires the science curriculum to give children an understanding of the complexities of the modern world, an appreciation of the way in which science works, and the thinking skills to make sound decisions. Gluckman saw these citizen-focused objectives as having increased importance in the 21<sup>st</sup> century. Gluckman went on to express doubts over the ability of the current science curriculum to fully address both of these objectives, and suggested they may require quite different teaching pedagogies in order to engage students during different stages of their education.

Internationally, these citizen-focused objectives have often been described as scientific literacy, which Erduran and Wong (2013) identified as a major aim of government policies and curriculum documents in many countries. Aspects of scientific literacy have much in common with NOS concepts such as the ability to solve problems and make evidence-based decisions. Duit and Treagust (2003) noted that the inclusion of scientific literacy in PISA (Programme for International Student Assessment) and TIMSS (Third International Mathematics and Science Studies) stimulated many countries to include these aspects in their curricula and to improve

the teaching of scientific literacy in the classroom. However, as researchers have found with NOS (Lederman, 2007), even when teachers supported the idea of scientific literacy, changing their practice in order to improve their effectiveness did not automatically follow.

The view that both the curriculum and pedagogy need to change in response to changing objectives is not a new one, with Fensham (1994) having argued the same point over twenty years ago. He suggested that although most agreed that some form of progression in content and understanding could be expected over the years, it was important to recognise that the purpose of science education also changed as students moved through school. For example, science in primary school should be about explaining concepts directly relevant to children's lives, while building scientific skills and making evidence-based decisions needed more emphasis later in high school. In a review of the implementation of the science curriculum in New Zealand, Gilbert and Bull (2013) agreed, suggesting that the focus in the early years of schooling should be on stimulating student interest in science, while during the middle years students should look at socioscientific issues relevant to their lives, and be encouraged to see themselves in careers involving science.

The inclusion of NOS in science curricula can be seen as a way of bringing together many of these competing objectives. If indeed teaching with a NOS perspective is more relevant and engaging for students, then more students will be more likely to learn and understand the content, and therefore be attracted into science-related careers. The use of explicit reflection about NOS should also improve scientific literacy and hence the capacity of students to participate in 21<sup>st</sup> century societies. Finally, as Millar and Osborne (1998) suggested, having the big picture concerning the way science works may counteract the disjointed and unsatisfying feeling that characterise the views of many school leavers, producing instead citizens who appreciate the value of science and its benefits to themselves and society.

### 3.3.7 The intended vs implemented curriculum

Clearly, the intent of many science curricula around the world is that NOS should be a regular part of students' experiences in the classroom, woven through all the content knowledge strands. However, when looking at curriculum changes in the past, researchers have consistently found that what is actually implemented in the classroom falls well short of the intended curriculum. Goodlad (1979) provided a useful framework for examining curriculum implementation, describing how the *formal* curriculum as originally intended by its designers was translated into the curriculum *experienced* by students. Goodlad explained that, in-between these stages, how the *formal* curriculum was *perceived* by those in the education system could vary widely, and what teachers actually did in the classroom, or the *operational* curriculum, varied even from this, as teachers did not necessarily deliver what they said they intended to teach. Thus the experienced curriculum was often considerably different from that which was originally intended. Goodlad suggested that in order to find out exactly what was actually being delivered, careful classroom observations were needed.

In studying curriculum implementation, many researchers have found large discrepancies between the aims of curriculum writers and their intended outcomes. Gardener (1975), for example, reported that many of the curriculum changes made in Australia and the United States over the preceding twenty years, had not achieved their stated aim of improving attitudes towards science in secondary schools. He suggested that it was not enough to simply introduce new content, methods or resources, but that significant effort must go into "changing the teacher behaviours which influence pupils' attitudes" (Gardener, 1975, p. 30). This view was supported by Bell et al. (1990) who described one response to the problem of curriculum implementation by a research team at Waikato University in New Zealand. The Learning in Science Project (LISP) aimed to provide in-service training to change teacher practice to a more constructivist, student-centred approach, as required by the curriculum. Bell et al. reported that to do this, teachers had to examine their own beliefs and theories of knowledge, including NOS, and that any change in curriculum or teaching pedagogy required substantial teacher professional development.

The vast sums of money spent by the National Science Foundation in the United States, between 1956 and 1975, were noted by Welch (1979). These funds were used for science curriculum reform and implementation and produced a whole host of new courses with modernised text books and equipment. However, Welch also noted that the school education system was extremely stable and difficult to change. Consequently the majority of science teaching across the United States looked much the same as it did before the reform initiatives started. Hodson (1988) also looked back on the previous quarter century of curriculum reform in American science, and suggested that while the intentions had been worthwhile the outcomes, or delivered curriculum, had been disappointing. Matthews (1989) too, strongly criticised the curriculum reforms over the previous thirty years which encouraged inquiry learning in science, but failed to achieve a key outcome – increasing the number of students who continued to study science.

A report which highlighted the difficulty of translating the formal curriculum into the one experienced by the students was provided by Tobin and McRobbie (1997). They described an in-depth study comparing the NOS views of one high school teacher in Australia with what actually happened in his chemistry class. The enacted curriculum turned out to be highly teacher centred, with transmission of knowledge to receptive students as the dominant pedagogy, despite the views of the teacher being more consistent with the more questioning, tentative NOS views, as described in the curriculum. The teacher saw no reason to change his approach as the students perceived it as successful. More recently, a study by Bartos and Lederman (2014) showed similar outcomes, with teachers valuing NOS but treating it differently from regular content in the classroom: for example, including no formal assessment of NOS. Tytler (2010) too, argued that a large part of the resistance to curriculum and pedagogical reform stemmed from existing science teachers commitment to, and valuing of content knowledge, supported by long experience of assessment that similarly valued the recall of content.

Agreeing with the findings of Tobin and McRobie (1997), Bartholomew et al. (2004), noted that even if teachers have a sophisticated understanding of NOS, this was no guarantee that they would be able to teach the concepts in the classroom. One reason for this, they suggested, was the difficulty of framing the key propositions of

NOS in an easily teachable manner. The researchers concluded that NOS ideas were best woven into activities that allowed students to construct knowledge and meaning for themselves. This required the teacher to choose suitable authentic activities, use open-ended questioning and be prepared to relinquish some control. None of this was easy for teachers used to delivering content in a structured, secure manner, generally replicating the way in which they were taught throughout their own science education. Added to these difficulties for teachers, Jenkins (1996) noted the problem curriculum writers themselves faced in the 1990s, trying to include NOS against the backdrop of conflicting interpretations of NOS by philosophers, historians and sociologists of science.

The requirement to pass high-stakes examinations has been identified as another barrier to the successful implementation of formal curricula that attempt to introduce new ideas such as NOS (Tytler, 2010). Bartholomew et al. (2004) described a yearlong project in the UK where the researchers worked to support a group of eleven teachers to implement some NOS concepts in their science classes. One of the key obstacles was the continuing dominance of content required in high-stakes examinations, and consequent teacher emphasis on the learning of facts. Spiller and Hipkins (2013) recommended that curriculum and assessment needed to be closely aligned if teachers were to implement the intent of the formal curriculum. They noted that even when teachers valued the NOS intent of the curriculum and were willing to try new strategies, they were still focussed on making sure students had the content needed to pass national assessments. Likewise, Venville et al. (2012) in summarising recent research, found that in regimes with high-stakes assessment, learning became more teacher centred and focused on the fragmented pieces of information needed for the test. The intent of the curriculum with its call to weave NOS throughout the content, was quickly lost.

Similarly, when Millar (2011) analysed the impact of the National Curriculum introduced in England, he noted that there were improvements in the participation rates of students in science up to the age of sixteen, which was an implicit aim of the curriculum. However, he expressed concerns over the quality of science education delivered, especially in secondary schools, as the pressure to perform in high-stakes examinations largely drove classroom

practice. The result in many schools was that teachers used past examination papers as their main curriculum guide and that, “practical work and class discussion were often reduced, sometimes almost to zero” (Millar, 2011, p. 171). Osborne (2007) too, expressed concern over the quality of teaching in science classrooms and argued strongly for the inclusion of scientific literacy and NOS in any 21<sup>st</sup> century science curriculum in order to improve the experiences of students in science. However, he recognised that it was very difficult to make real changes in classroom practice as teachers had to combine several elements stating: “Only an approach that interrelates these three elements – curriculum, pedagogy and assessment – can ensure that students are offered a fundamentally different experience from that which currently predominates throughout the world” (Osborne, 2007, p.182).

As discussed in Chapter 2, there is considerable agreement and research on successful pedagogy for delivery of NOS, and the inclusion of NOS in most current science curricula indicates a recognition of its importance by governments, but the assessment of NOS, particularly in high-stakes examination systems, still requires considerable work.

One key requirement for the successful translation of the formal curriculum into the curriculum actually experienced in the classroom is the provision of considerable support and professional development for teachers. Crawford (2014, p. 537) maintained, “... simply creating policy documents and new curricula *without attention to robustly supporting teachers*, will not necessarily change the way we traditionally teach science.” Bybee (2010) too, argued that professional development of teachers had to be an integral part of any curriculum reform. Another research project looked at science curriculum implementation around the world with a focus on developing countries (Col & Taylor, 2012), with the authors concluding that professional development of teachers was crucial. There are, however, many localised examples of successful professional programmes that are able to translate NOS from the formal curriculum into the classroom (Lederman & Lederman, 2012; Erduran & Wong, 2012; Freire et al., 2013), but achieving this on a national scale over an extended time period appears to be exceedingly difficult.

### **3.3.8 Summary of curriculum implementation and NOS**

The benefits of including of NOS ideas in science curricula have been advocated almost since the beginning of universal public school education (Dewey, 1934), but have appeared more formally and explicitly in curriculum documents around the world over the last twenty years. One of the key aims of these curricula has been to prepare students for life in the 21<sup>st</sup> century, recognising that the pace of technological change has increased and countries need citizens who can think critically and creatively. NOS is seen as crucial to fostering this type of thinking. However, another important aim of many new science curricula is to increase the engagement of students with science, so they see the value of their learning and continue on with science subjects. The aim of this thesis is to investigate whether incorporating NOS into the curriculum as experienced by students actually achieves this aim of increased engagement with science. In relation to this, Chapter 4 describes the methods used to in investigate this aim, while both Chapters 5 and 6 provide analysis of the results and a discussion concerning the effects of the curriculum on engagement, as experienced by students in the classroom.

## **CHAPTER 4    Methodology**

### **4.1 Introduction - personal reflections**

In this research project I was well aware that as the sole researcher I was responsible for the collection and analysis of all the data, so needed to ensure there was sufficient reliable information for sound interpretations to be made. As Merriam (2009) indicated, a key element of qualitative research is that a person collects the data, whether that person is part of a team or working as an individual. The advantages of this are that the researcher can respond and adapt to situations encountered, in order to derive as much meaning as possible from the data. They are immersed in the situation and will be able to pick up information directly from the participants without it being filtered by remote surveys and statistical analysis. However, a problem with the researcher being so involved in the study is that their own biases and preconceived ideas may impact on their findings. This subjectivity needs to be acknowledged by the researcher and their changing viewpoints be documented as the project develops as a series of personal reflections about the meaning of the data (Creswell, 2008). Therefore, this section begins with some information about my own background and views regarding NOS.

My journey towards this research project is described in Section 1.1, but I include some more details and reflections here which are relevant to the methods described. I bring to this research project over twenty years' experience as a science teacher, mainly working in New Zealand, but with time spent in the United Kingdom and the Caribbean. My teaching philosophy has always been to try and make science relevant and interesting to the students and I have welcomed the introduction of NOS in the New Zealand science curriculum. My views on NOS have been strongly influenced by experiences gained while the recipient of New Zealand Science, Mathematics and Technology Teacher Fellowships (The Royal Society of New Zealand, 2002). These allowed me to work for a year in different science environments and see first-hand how science works in the world beyond the school laboratory.

In 1994 I worked at the University of Canterbury as part of a chemistry research group attempting to discover useful pharmaceuticals from compounds isolated from

marine sponges. In 2009 I worked at Syft Technologies (Syft Technologies, 2004), a high-tech start-up company making an instrument that detects volatile organic compounds down to parts per billion. It was particularly this more recent experience that convinced me of the need for my school students to have a deeper understanding of NOS issues. The way the science used in this new instrument was developed from pure academic research, and the challenges faced in bringing the product to market, seemed to encapsulate all the educational research I had been reading about NOS. I felt that students needed to hear these sort of stories, for all the reasons described in the literature and desired by government agencies: becoming scientifically literate, being able to participate in our science based democracies, and to generate wealth and income, personally and nationally.

## **4.2 Research design**

Educational research is a form of disciplined enquiry that must stand up to scrutiny applied to data collected and conclusions or interpretations made (Shulman, 1997). Shulman went on to explain that although there was considerable agreement about the nature of educational research there were continuing arguments about research methods. To stand up to scrutiny he stated that, “The best research programs will reflect an intelligent deployment of a variety of research methods applied to their appropriate research questions.” (Shulman, 1997, p.13). This view was supported by Onwuegbuzie and Leech (2005) who strongly advocated for a mixed methods approach to research in the social sciences, stating that, “By utilizing quantitative and qualitative techniques within the same framework, pragmatic researchers can incorporate the strengths of both methodologies” (p. 385). These views also fit well with a NOS approach as both Kuhn (1961) and Feyerabend (1975) pointed out, there is no one scientific method, so scientists use a wide variety of techniques to answer their questions.

I have used this pragmatic approach in my research project as combining quantitative and qualitative data enables deeper understanding of the research problem (Creswell, 2008). Inferences and explanations in this mixed methods research design were made from a constructivist-interpretive paradigm, whether the data was collected using quantitative or qualitative techniques. Table 4.1 gives an overview of the research

process, indicating how the methods, ethics and quality standards of the project fit into the research design, paradigm and epistemology.

Table 4.1

*An overview of the research process*

Aspect of the research process	Approach taken in this study
Epistemology	Constructivist
Research paradigm	Interpretive
Methodology	Mixed methods case study, with elements of action research
Data collection	Closed questionnaire <i>TOSRA</i> Open questionnaire <i>VNOS-D</i> Semi-structured interviews Classroom observations
Data analysis/interpretation	Profiles of VNOS Iterative examination of transcripts Identification of common themes Statistical summaries Significance tests Box and whisker plots
Quality standards	Triangulation of data Recognition of researcher bias Member checking Rich descriptions
Ethical issues	Researcher-participants relationships built on trust and respect Informed consent and confidentiality Benefits to participants

As described in Section 1.5, a case study approach was well suited to this research project as it was limited to one year group in one school. A major purpose of this research was to point out to teachers what works in the classroom and this has been

recognised as one of the advantages of case study methodology (Cohen et al., 2011, p. 292):

Case studies are a 'step to action'. They begin in a world of action and contribute to it. Their insights may be directly put to use; for staff or individual self-development, for within-institutional feedback; for formative evaluation; and in educational policy making.

These comments are particularly relevant to my own situation as I was working in my own school, using a process of feeding back information directly to the staff involved to try and improve student engagement. Anderson (1998) agreed that education is a process, and that case studies are process-oriented, able to adapt and respond to the changing circumstances of the participants.

This was certainly the case throughout my research, as for example I prepared experiments with guidance for teachers to help make NOS explicit, a response to the need for support which emerged from the interviews and observations. This study can also be described as using action research design which as Creswell (2008) explained is often used by teachers to improve an area of practice within their school. The key aspects of this research design include having a practical focus, collaboration with other staff and feeding back findings to make improvements to teaching and learning. Cohen et al. (2011) acknowledged these aspects and added that action research helps improve the competency of the participants, seeks to explain or understand the problem and is often tackled through a case study. All these characteristics of action research can be seen in this project, the focus being the exploration of any links between NOS and engagement, which required collaboration between all science staff, the ultimate aim being improvement of both student engagement and NOS knowledge.

### **4.3 Programme setting and selection of participants**

This study was based in one large co-educational secondary school in Christchurch, New Zealand. The school draws the majority of students from its immediate neighbourhood, with a cross-section of socio-economic and ethnic groups

represented. The staffing, resources and school structures are typical of government funded schools throughout the country, and in many Western economies.

As described in Chapters 1 and 3 the new science curriculum (Ministry of Education, 2007a) was supposed to be fully implemented in 2010 with NOS an overarching strand. The reality had been a gradual implementation of the new curriculum involving the re-writing of units to match both the new ‘front-end’ requirements of the general curriculum and the NOS requirements of the science curriculum, as illustrated in Figure 4.1. Staff were assigned specific units and asked to write schemes of work in a common format and organise teaching resources in electronic folders that were shared between all staff. The units all had a ‘big picture’ focus, with NOS elements added as they were developed. Some examples of the units are outlined in Table 4.2.

Table 4.2

*Examples of topics taught in Year 9 Science.*

Old unit	New unit	Big picture focus
Plants	Food or Fuel	Plants capture solar energy through photosynthesis. Humans use plants as food and fuel.
Nature of Matter	Fabulous Fragrances	Particle theory of matter. Links between perfumes and the movement of particles.
Light	Radiation and the Body	Energy can travel through electromagnetic radiation. How does electromagnetic radiation affect our lives?

On my return from working in industry in 2009 I started each year with a presentation for science staff on the big issues facing science and society, and encouraged them to use this approach in their classes. At regular science faculty meetings throughout the year issues related to NOS pedagogy were discussed through sharing activities, teaching approaches or assessment methods used in the

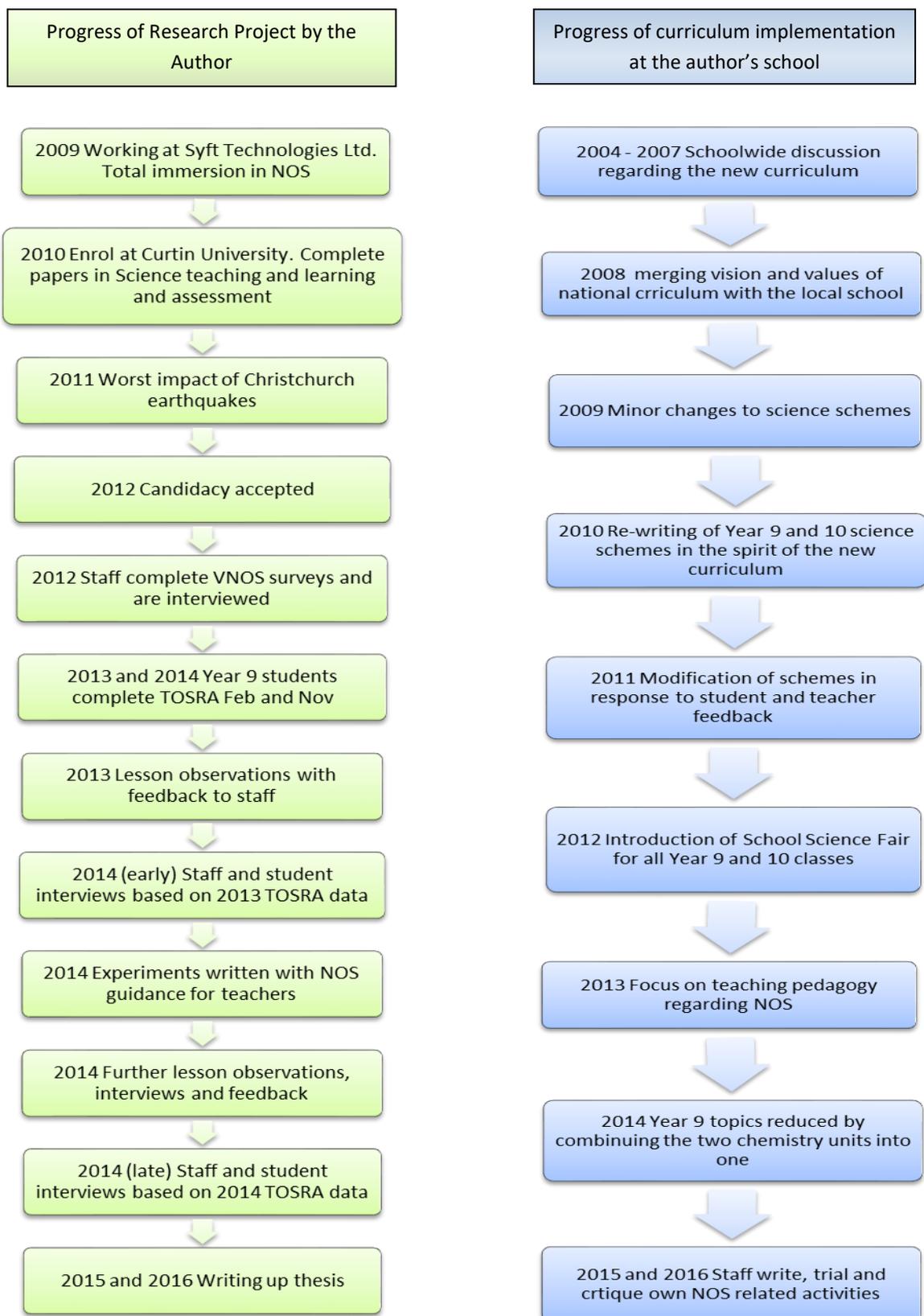


Figure 4.1.

Flow chart comparing progress on curriculum implementation with the research project.

new units. So, the setting of the research programme was one of continuous staff professional development about NOS, with feedback from my research findings used to inform practice.

Students at the school are placed in Year levels from 9 to 13, with Science a compulsory subject in Years 9 to 11. Year 9 students are generally twelve to fourteen years old, experiencing their first year of secondary schooling, and come from a wide range of primary and intermediate schools, with most receiving specialist science teaching for the first time. Initially I intended to follow one cohort through Year 9 and 10, but as the project developed I decided to focus on two successive Year 9 cohorts as this allowed two sets of data to be collected related to the same scheme of work. In 2013 there were fifteen Year 9 classes totalling 404 students, while in 2014 there were fourteen classes with 374 students. All students were necessarily involved in this study, because they were part of the whole Science Faculty drive to implement the curriculum which included a NOS component.

The Science Faculty consisted of a mixture of eighteen full- and part-time teachers. In 2013 ten different staff members taught Year 9 classes, while in 2014 there were twelve staff teaching Year 9 classes. Details of the background and experience of the staff involved are given in the Section 4.4.1 and Table 4.3.

#### **4.4 Instruments used**

##### **4.4.1 Views of Nature of Science (VNOS)**

In order to establish the level of understanding of the teaching staff concerning NOS, and hence answer the first part of research question three, the VNOS-D instrument developed by Lederman (2007) was selected. This instrument consisted of ten open-ended questions requiring written responses to probe understanding (see Appendix A). The VNOS-D is a variant of other similar instruments used by Lederman et al. (2002) with the changes introduced to shorten the task so that it could be completed in an hour, while producing the same results as its predecessors, VNOS-A, B and C. The use of this instrument supported by semi-structured interviews is well established as a method of obtaining valid and reliable views on NOS (Lederman,

2007). Section 2.4 has more detail on the development, use and limitations of instruments for measuring VNOS.

I started the process of establishing teachers' views of NOS in 2012, well before classes were allocated for 2013. Consequently, I did not know which teachers would have Year 9 classes, so I explained the project to all staff and gave them a consent form, an example of which is in Appendix E. All those who signed and returned the consent form completed the VNOS survey. I found the responses to the VNOS-D and subsequent interview so useful to me both as a researcher and as the Head of Science Faculty, that I repeated the processes with new staff over the period of the project. Table 4.3 shows the eighteen staff who completed the VNOS-D instrument over the three years of the project, during which time there were a total of twenty-two science staff, some of whom were only at the school temporarily.

The procedure for administering the VNOS-D was as follows:

I gave out the VNOS-D form electronically with an option for a print version if desired. I specified that the task should take a maximum of fifty minutes to complete so staff did not feel obligated to spend too much of their valuable time on the task. Some teachers asked for clarification about the questions and were concerned that they might not have the 'right answers'. To this I responded that I was interested in their current knowledge and understanding about NOS and that they should simply put down what they knew or felt about each question. Lederman et al. (2002) specifically stated that VNOS questionnaires were not suitable for summative assessment as this might cause participants to alter their responses in order to produce correct answers. All teachers were aware that their view about NOS would be discussed during the follow-up interviews, so there was no need to spend more than fifty minutes on the written task.

Once the VNOS-D forms were returned the responses were analysed using the broad NOS themes drawn from research as summarised in Table 2.1. An initial profile for each teacher was created which described their views on NOS under each of the broad themes. Views for each theme, such as tentative NOS, were envisaged as lying along a continuum:



culture of argumentation, or how well claims are argued, rather than if they fitted a preconceived notion of what views of NOS should be. This suggestion was used to help formulate specific questions to use in the interview, as described in Section 4.5.

There was one NOS theme added to Table 2.1 near the end of the data collection phase as a result of the lesson observations, that of Cooperation and Collaboration. It was noted that every teacher used group work during their lessons, whether carrying out experiments or research, or when discussing and debating ideas. The importance and relevance of the NOS theme Cooperation and Collaboration in the school laboratory therefore became obvious as it was very much a part of regular practice. However, like many other NOS themes the teachers did not link this regular practise to NOS explicitly. Although cooperation and collaboration had been identified by Osborne et al. (2003b) as a key factor in the way science and scientists work it was not originally included in the list of NOS tenets in Table 2.1 as it was not specifically mentioned by other researchers, such as Lederman (2007) or Deng et al. (2011). I felt that the ease with which teachers could use this theme in class to make NOS explicit made it worth adding to the list of NOS themes that teachers should aim to deliver. However, the result of this retrospective decision was that evidence for the teachers' views concerning Cooperation and Collaboration as a NOS theme was not gathered at the same time as the analysis of the VNOS surveys was done for the other nine themes. Nor were any questions directly asked about this theme during the teacher interviews concerning the VNOS surveys.

A final point concerning the VNOS-D survey is that it was only used with the teachers, not students. The focus of the research was to find out if the engagement of students was affected when NOS ideas were introduced into science lessons, rather than if the students gained increased understanding of NOS. Thus, the VNOS survey was used to establish the teachers' understanding about NOS, and then the TOSRA survey and lesson observations used to discover if students were engaged when teachers used NOS concepts in their classes.

## **4.4.2 Test of Science Related Attitudes (TOSRA)**

### **4.4.2.1 Introduction to TOSRA**

The Test of Science Related Attitudes (TOSRA) (see Appendix B) instrument developed by Fraser (1978a) was selected in order to provide data on students' attitudes towards science, and hence their level of engagement with science lessons. Background for the use of TOSRA for this purpose can be found in Section 3.2.3, a strong justification being the established validity and reliability of the instrument through its use in many studies (Blalock et al., 2008; Haladyna & Shaughnessy, 1982). Although the TOSRA could be used to examine the attitudes of individual students, Fraser (1981) suggested that it is best suited for use with larger groups to look for changes due to curriculum implementation, as was the case in this project. The TOSRA is a closed response seventy item questionnaire consisting of seven subscales as shown in Table 3.2. The participants' responses to each item were recorded on a five point Likert scale ranging from 'strongly agree' to 'strongly disagree'.

Arguments for and against the use of closed response survey instruments have been given in Sections 2.4 and 3.2, which describe the development and use of similar instruments for use in NOS, engagement and attitude research. The main advantages of survey instruments such as TOSRA were summarised by Jenkins (2006) as being suitable for large samples due to their low expense, ease of use, and amenability to statistical inference. Disadvantages included limiting responses through closed questions, and providing items that reflect the developers' bias (Aikenhead & Ryan, 1992; Lederman 2007). There can also be significant problems interpreting the information gained, with warnings against combining data from different constructs into a single score, and viewing each item as having equal weight provided by Creswell (2008) and Reid (2011). Finally, Abd-El-Khalick and Lederman (2000) pointed out the problem of using an instrument designed in the 1960s or 70s for research many years later. Their concern was that the conceptions used to formulate statements concerning NOS at one time, may well have changed over time. This problem does apply to a degree with the TOSRA, specifically in the subscale,

Leisure Interest in Science, where there is no mention of internet or computer based activities.

#### 4.4.2.2 Pilot study

Given all these factors I decided to run a small pilot survey prior to the full use of the TOSRA with all Year 9 students, a technique recommended to identify any problems so modifications can be made if needed (Cooley & Klopfer, 1963; Creswell, 2008). A group of six Year 10 classes across a range of abilities were chosen with teachers who were willing to cooperate. Ethical consent forms were handed out in class to those students who were interested and with the cooperation of a variety of teachers across different subjects the students completed paper copies of the TOSRA. See Table 4.4 for details of the students and classes involved in the pilot study.

Table 4.4

*Student numbers and classes involved in the TOSRA pilot.*

Class	Ability	Number of students in class	Number returned ethics form	Number completing TOSRA
10a	Medium	28	7	7
10b	Medium	29	5	5
10c	High	28	17	17
10d	Medium	28	0	0
10e	Low	17	0	0
10f	Med/low	19	1	0

Students completing the TOSRA were invited to comment on the test itself. The problems that emerged from this pilot study with comments and proposed solutions were as follows:

- Low numbers of students willing to participate and return consent forms. The timing was poor at the end of the school year, after examinations with many students involved in other activities and reluctant to do another test. The subsequent survey of Year 9 classes was done at the start of the year and clear

explanations were given to the students of the benefits of the research, including the aim of improving their own experiences in science classes.

- The layout of the TOSRA kept the items organised into groups of ten under the heading of each subscale, thus students could adjust their answers to fit a desired outcome if they so wished. For the final study the TOSRA was modified to remove the subscale headings and randomly distribute the items from each subscale throughout the whole document.
- A small number of items had no response from the student. These were assigned a score of '3' signifying they neither agreed nor disagreed with the item, a technique suggested by Fraser (1981). Instructions were given to teachers and students in the main survey to check that they had filled in an answer to every question. Later in the research process an online version of the TOSRA was developed which was given as an option to some classes and this ensured that every item had a response.
- One student noted the sexist language used in one item: "If you met a scientist, he would probably look like anyone else you might meet". This was changed from "he" to "she/he".
- Some formatting problems in the TOSRA document used were evident from student responses. That is, in some instances the item statement and the area for responses did not exactly line up. This was corrected so that for each item it was completely clear where the response should be placed.

Having collected the data from the pilot study it was entered into a spread sheet and a brief statistical analysis carried out for each of the subscales. This was compared with data from the original development of the TOSRA (Fraser, 1978a) to see if the results were within reasonable limits. Although the pilot scores were in general slightly higher than Fraser's results they were all within one standard deviation of the original Year 10 mean scores. Given the limitations that the students in the pilot study were keen volunteers and were only a small sample, the results gave me confidence in the TOSRA, so with the modifications mentioned it was used in the main study.

#### **4.4.2.3 Main study TOSRA, first year**

At the start of the school year in January 2013 I outlined the whole research project to all the science staff. Many had already completed the VNOS survey and been interviewed by me the previous year, so had a good understanding of the aims of the project and were very supportive. Results from the pilot TOSRA study and the VNOS interviews were presented and discussed, resulting in the following procedure for administering the TOSRA:

I visited every Year 9 science class at the start of the school year and explained the aims and requirements of the research project and distributed consent forms to all students See Appendix E for the consent form given to students.

All Year 9 students completed the TOSRA survey in a regular science period after three weeks of the school year. The numbers of students involved, the proportion who returned consent forms and their teachers are shown in Table 4.5. The class type in the table refers to ability groupings or streaming as determined by entrance testing in Mathematics, English and Reasoning skills. The very high proportion of students returning consent forms in some classes indicated support for the research project by the students and gave the findings more credibility as being representative of the year group. Reid (2011) suggested that the validity of findings when comparing two groups using attitude instruments carries more weight when the sample size is above 200, and with a total of 300 students returning consent forms this recommendation was clearly satisfied.

The final layout of the TOSRA, following changes made as a result of the pilot study, is shown in Appendix B. Fraser (1981) recommended that to ensure that the responses from students are a genuine reflection of their beliefs, they be told that the results of the TOSRA would not be used for any grading purpose. This was made clear to all the classes and that the inclusion of their name was simply to make sure no data was missed.

Table 4.5

*Teachers and classes involved in the TOSRA survey in 2013 (\* C2 replaced B8 after two terms).*

Form class pseudonym	Teacher pseudonym	Type of class	Response type: Start/end of year	Number in class	Number of consent forms returned
9A	B1	Extension	Paper/online	29	24
9B	B8/C2*	Top band	Paper/online	28	23
9C	B7	Top band	Paper/online	31	30
9D	P5	Mid band	Paper/online	30	29
9E	B1	E-learning	Paper/online	29	17
9F	P1	Mid band	Paper/online	30	28
9G	B5	Mid band	Paper/online	29	26
9H	B5	Mid band	Paper/online	28	18
9J	B4	Mid band	Paper/online	30	21
9K	B7	Mid band	Paper/online	28	24
9L	B2	Mid band	Paper/online	26	21
9M	B2	Mid Band	Paper/online	28	20
9N	B3	Mid band	Paper/online	26	5
9P	B3	Literacy support	Paper/online	16	9
9Q	P2	Literacy support	Paper/online	16	5
				404	300

Data from the TOSRA forms was entered into a spread sheet, with the following measures taken to reduce the chance of input error:

The papers for each class were arranged alphabetically and checked against the name in the spread sheet before entering.

Data input was in groups of ten items, with regular checking to ensure the data was entered for the correct item.

Each response was assigned a score, with positively worded items scored 5, 4, 3, 2, 1, for responses ranging from strongly agree to strongly disagree, while negatively worded items were scored 1, 2, 3, 4, 5, respectively. The items belonging to each scale and the assignment of a positive (+) or negative (-) orientation are shown in Appendix B.

Once the data for all students was completed it was organised by form class and a total score assigned to each student. The class list was returned to each science teacher to do a quick check and see if the students with the highest and lowest TOSRA scores did appear to be the most and least positive students. Teachers were also asked if there were any obvious anomalies, such as an extremely keen and positive student in class who had a low TOSRA score. The teachers reported that the TOSRA scores did generally reflect their initial impressions of the students but there were some anomalies between teacher impressions and TOSRA scores. I re-entered the data for three of these apparent anomalies and compared it with the original scores. There were no discrepancies in the TOSRA scores so I was confident that data had been entered accurately.

The procedure for administering the TOSRA at the end of the school year essentially repeated steps 1-5 above, with the following modifications.

An online version of the TOSRA was created and teachers were asked to take their class to a computer room to complete the TOSRA electronically. This was done to make data entry and processing easier, and fitted with e-learning initiatives being promoted across the whole school at the time. An additional free response question was added at the end of the survey: “Thank you for completing the survey. Your time and responses are much appreciated. Feel free to write any comments in the box below about this survey or your experiences in science this year”.

Classes completed the TOSRA in the last month of the school year, after the junior examinations, which tested students on their learning in all subjects.

The electronic data for the whole Year 9 cohort was processed together using an Excel spreadsheet (negative scores reversed, items re-organised into subscales), then divided back into class groupings. The processing was repeated for two classes individually as a check on the bulk data processing. Three errors out of 4130 data entries were identified as a result of this check, where for example a “2” had not been

changed to a “4”. This level of error was deemed sufficiently low to continue using the data without further checks.

Finally, the data from the electronic spreadsheet was processed using iNZight statistical software (iNZight, n.d.), a free programme developed at the University of Auckland designed to calculate key statistical information and produce graphical representations of data. The software allowed each TOSRA category to be analysed separately, calculating mean values, standard deviations plus an analysis of variance test. This produced statistical measures (F- and p-values), of the significance of variations between mean values obtained at the beginning and end of the year. Interpretation and analysis of the statistics generated from the TOSRA data are given in Chapter 5.

#### **4.4.2.4 Main study TOSRA, second year**

At the start of the second year of the main study in 2014, I again discussed the project with all the science staff and presented a summary of the research findings to date. The procedure for administering the TOSRA was the same as for the beginning of the first year with the following changes. Both electronic and paper versions of the TOSRA were made available to teachers to use with their classes. This was to provide them with the flexibility for them to complete the TOSRA in the first three weeks of school, some classes having difficulty accessing the computer resources needed. The numbers of students involved, the proportion who returned consent forms and their teachers are shown in Table 4.6. The free response item at the end of the electronic survey was changed to: “Thank you for completing the survey. Your time and responses are much appreciated. Feel free to write any comments in the box about your experiences in science before High School”.

As in the first year I returned class summaries of the TOSRA scores to the teachers to check whether they reflected their impressions of the students and to use the information in their class specific planning. Teachers reported that generally the TOSRA scores did reflect their view of the students, with high scoring students showing enthusiasm in class, as discussed more fully in Section 5.3.3.1.

Table 4.6

*Teachers and classes involved in the TOSRA survey in 2014 (\*Teachers who replaced the original teachers during the year).*

Form class pseudonym	Teacher Pseudonym	Type of class	Response type start/end of year	Number in class	Number of Consent forms returned
9A	B1	Extension	Online/online	29	26
9B	B3	Top band	Paper/online	30	27
9C	B5	Top band	Online/online	27	27
9D	C2/B2*	Mid band	Paper/online	30	27
9E	B9	Mid band	Paper/paper	28	28
9F	B1	E-learning	Online/online	27	18
9G	P5	Mid band	Online/online	30	30
9H	P1	Mid band	Online/online	27	21
9J	P4/B4*	Mid band	Paper/online	27	15
9K	B6	E-learning	Online/online	27	19
9L	B6	Mid band	Online/online	25	14
9M	C1	Mid band	Paper/online	30	29
9N	P2	Literacy support	Online/online	23	16
9P	B10	Literacy support	Online/online	14	11
				374	309

At the end of the second year the TOSRA was given to classes before the junior examinations with the aim of eliminating some of the negative feeling towards doing the survey that some students reported in the first year. Teachers were again given the option of completing the survey using a paper or electronic copy, and the final open-ended item was re-worded to: “Thank you for completing the survey. Your time and responses are much appreciated. Feel free to write any comments in the box below about your experiences in science this year”. The same data entry and processing techniques were carried out as in the first year, using Excel spreadsheets

and iNZight statistical software, with details of the subsequent analysis given in Chapter 5.

#### **4.5 VNOS teacher interviews**

The importance of conducting interviews to investigate the views of NOS revealed in written responses to VNOS instruments was emphasised by Lederman et al. (2002, p. 517) who stated, “Whereas face and content validity of the various versions of the instrument have been determined repeatedly, its principle source of validity evidence stems from the follow-up interviews.” They also recommended that researchers using the instrument for the first time should interview all of the respondents, which is the procedure that I adopted. This approach was also supported by Chen (2006, p. 817) while developing a new instrument to measure views on NOS, who stated, “multiple methods are recommended to draw systematic and valid conclusions about subjects’ NOS views”.

Although the primary purpose of the interview was to validate the written evidence provided on the VNOS-D questionnaire, there were other questions I included to discover where their NOS views originated, how they viewed the incorporation of NOS into their teaching practise and what their professional development needs were regarding NOS. These questions helped to answer research Questions 1 and 3 concerning the perceptions and use of NOS by teachers. Lederman and O’Malley (1990) described a similar approach, using interviews to not only find out the students’ views on NOS, but the sources of these views and how and why they might have changed.

A generalised interview protocol was drawn up based on an exemplar provided by Creswell (2008, p. 234), to guide the follow-up interviews. This was adjusted for each individual, depending on their written responses to the VNOS-D instrument. Appendix D contains the interview protocol used for teacher C4. Interviews took between thirty and fifty minutes, were carried out in a quiet office and recorded using a digital voice recorder. Interview techniques were used as suggested by Creswell (2008), including, making sure the interviewee did most of the talking, and keeping them focussed so that the time was used efficiently. Although I knew some

background information about each teacher, giving them a chance to tell me about their experiences related to NOS on the way to becoming a teacher proved particularly valuable for me both as a researcher and the Head of the Science Faculty.

Further questions were used to probe answers given, such as, “Could you explain your response further?” or “What do you mean by that?” Lederman et al. (2002) recommended this use of probing questions, and added that that the interviewer should avoid giving directive clues in their questions, but use extended wait time to ensure the interviewee gave genuine well thought out answers. These techniques were used with all those that completed the VNOS written survey as shown in Table 4.3. The interview recordings were then transcribed, analysed and combined with the written information from the VNOS-D instrument to provide a more detailed description of the participants’ views of NOS. These descriptions were shared with the participants in a process described by Guba and Lincoln (1989) as member checking, to ensure that that written interpretations were consistent with the actual views of the participants. The participants first read the summary of their views on NOS and then had the opportunity to discuss these with me. In all cases they agreed that the descriptions were a fair representation of their views. Analysis of the transcripts and subsequent discussion of the findings can be found in Chapter 5.

#### **4.6 TOSRA interviews**

Once the quantitative data from each year had been collected and analysed it was used to provide stimulus material for interviews with teachers and students in selected classes. This was done to collect evidence for all three of the research questions, and as a form of triangulation as recommended by Mathison (1988). The interviews also provided a way of gaining a deeper understanding of the attitudes and therefore possible engagement of the students with science lessons. Creswell (2008) suggested that using a qualitative technique such as interviews enhances the quantitative data by providing detailed contextual information. Thus the intention was to gain greater insight by integrating the two forms of data.

#### **4.6.1 Teacher interviews regarding TOSRA results**

In the first year of the study, quantitative data from the TOSRA was summarised for each class and given to the teachers the following school year. The time delay was unavoidable as the students only completed the TOSRA right at the end of the school year so there was insufficient time to process the data before the summer break.

Despite this gap of up to four months between the second TOSRA and interviews with staff, their memory of their classes and individual students was good, as shown by selected excerpts from the transcripts given in Chapter 5. The data given to each teacher included a comparison of TOSRA scores from the beginning and end of year surveys for each student in the class, plus subscale averages for the whole class. Individual students with particularly high or low TOSRA scores, or whose scores had changed significantly over the year were also included. The teachers were given a set of general questions which were asked during the interview based on the quantitative data, although additional questions were asked as the interviews unfolded. Appendix D contains an example of the interview protocol used. Interviews were arranged with those staff who were still at the school and willing to participate. As shown in Table 4.7 this resulted in eight out of the eleven teachers involved in the first year, covering twelve out of the fifteen classes. Interviews were shorter than the VNOS ones, varying in length from eleven to twenty-three minutes, as I was conscious of using up precious teacher time, an important consideration from an ethical point of view

An audio recording of each interview was made and transcribed with summary comments. This was given to the teacher concerned for member checking with the opportunity for further comment or amendment. All teachers were satisfied that the transcription and comments constituted a fair representation of their views during the interviews. Analysis of the transcripts and subsequent discussion of the findings can be found in Chapter 5.

Table 4.7

*Teachers interviewed regarding TOSRA results for their classes in 2013.*

Teacher	Classes
B1	Extension and E-learning
B7	Top and mid band
P4	Upper mid band
B2	Two mid band classes
P1	Mid band
B4	Mid band
B3	Lower mid band and literacy support
P2	Literacy support

In the second year of the study the same process was followed as described above. There were however two differences. Firstly, the follow-up interviews were carried out in the same year, as the students completed the TOSRA survey. Secondly, two extra questions were added to the interview protocol:

- How effective do you think the Nature of Science strand in the NZ science curriculum is in terms of engaging Year 9 students in science lessons?
- Have your views concerning NOS and/or its place in the curriculum changed as a result of being involved in this research project?

These questions specifically targeted Research Questions 1 and 3. Teachers interviewed in the second year are shown in Table 4.8, with six out of the fourteen teachers involved in the year interviewed covering eight out of the fourteen classes. The consistency provided by four of the teachers (B1, P1, P2, P5) being involved and interviewed in both the first and second years was very useful in making comparisons between the TOSRA data for the two year groups, thus helping to improve the reliability of the research findings.

Table 4.8

*Teachers interviewed regarding TOSRA results for their classes in 2014.*

<b>Teacher</b>	<b>Classes</b>
B1	Extension and E-learning
C1	Mid band
P4	Mid band
P1	Mid band
B6	Mid band and E-learning
P2	Literacy support

#### **4.6.2 Student interviews regarding TOSRA results**

The purpose of the student interviews was twofold. First, they served as check on the validity of the responses to the TOSRA survey, which helped to answer Research Question 1b concerning NOS and engagement. Secondly, they provided evidence towards research Question 2, finding out directly from the students which teaching strategies they found most engaging. Ebenezer and Zoller (1993) used a similar interview technique to probe more deeply the information revealed in their questionnaire about attitudes to science. They were able to find out why these attitudes were held, which they found more useful than just knowing what the attitudes were at a particular instant.

As with the teacher interviews, TOSRA data was used as the basis for constructing an interview protocol with individual students. The students selected were those with significant changes in their TOSRA scores over the year, or who appeared to have particularly high or low scores compared with others in their class. Table 4.9 shows the students interviewed regarding their TOSRA results in the first year, with some details relevant to their selection. These students had teachers whom I had already interviewed, both concerning their views on NOS and regarding their class' TOSRA results. This allowed me to better triangulate information, gaining teacher and student perspectives from the same class.

Table 4.9

*Students interviewed regarding their TOSRA scores in 2013 (student codes starting with the same letter were in the same class).*

Student Code	Class type	Teacher	TOSRA results over the year
L1	Mid band	B2	Low with large increase
L2	Mid band	B2	Neutral with large increase
M1	Mid band	B2	High with moderate decrease
M2	Mid band	B2	Very low with slight increase
E1	E-learning	B1	Very high and remained high
E2	E-learning	B1	Very low with slight increase
E3	E-learning	B1	High with moderate decrease
E4	E-learning	B1	Very high with large decrease
D1	Mid band	B7	High with moderate decrease
N1	Top band	B7	High with moderate decrease
H1	Mid band	P1	High with moderate decrease

The Year 9 students interviewed were between twelve and fourteen years old, and as Partington (2001) noted, extra care must be taken by the interviewer in order to gain meaningful responses from children. The power imbalance between the child participant and the adult interviewer can lead to responses designed to please the adult rather than answers that reflect the beliefs of the child. I adopted the strategies recommended by Partington, such as giving supportive nods to encourage longer explanations, repeating statements to reassure the students I was listening and hearing correctly, and asking follow-up questions to check understanding. Cohen et al. (2011) also made a number of recommendations which I adhered to for interviews with children. These included, keeping the interviews short and distraction free, using straightforward language, and above all putting them at ease by valuing their responses and assuring them that their comments would be confidential.

The interviews were held in a quiet office and varied in length from eight to twenty minutes. The students were all very willing participants, seemed genuinely interested in the process, and were comfortable enough to offer comments and criticisms regarding their teachers and experiences in science classes. Two examples from TOSRA interview transcripts show this willingness to criticise, indicating the trust they placed in me to keep the information confidential:

*D1: The teacher, [B7], she was a little bit over the top, sometimes .... It kind of annoyed me. And there were lots of other little things [about her] that just really started to annoy me.*

*L2: Well ... we did a lot of writing and like copying from the projector and stuff. I didn't think it was like, helping us learn as much.*

An audio recording was made of all the interviews and subsequently transcribed, with detailed analysis of these given in Chapter 5. A written summary of the interview was given to each student with an opportunity to comment or amend. Only one student suggested a change in the transcription, indicating that they did not think they used the word 'like' as much as had been recorded!

As with the interviews with teachers concerning the TOSRA results from 2013, the students were interviewed early the following year. Once presented with their own TOSRA data these students seemed to have no difficulty in remembering their feelings and key moments from the previous year. In 2014 all the interviews were conducted within six weeks of the students completing the second TOSRA survey. Table 4.10 shows the students interviewed based on TOSRA results in the second year, with some details relevant to their selection.

Table 4.10

*Students interviewed regarding their TOSRA scores in 2014 (student codes starting with the same letter were in the same class).*

Student Code	Class type	Teacher	TOSRA results over the year
J1	Extension	B1	Very high with moderate decrease
J2	Extension	B1	High with moderate increase
R1	Mid band	B6	High with moderate decrease
R2	Mid band	B6	High with moderate increase
S1	Mid band	B6	High with large decrease
S2	Mid band	B6	Neutral with moderate increase
V1	E-learning	B1	High with very large decrease
W1	Mid band	C1	High with very large decrease
W2	Mid band	C1	Low with very large increase

#### **4.7 Classroom observations**

Classroom observations were absolutely crucial to answering parts of all three research questions. Empirical evidence was needed to determine if NOS was being delivered in classes, and if so what strategies were used, and were they effective in engaging students. Crawford (2005) strongly argued for inclusion of observations in educational research, noting that only by observing students in their natural classroom was it possible to see what they actually do and understand. Cohen et al. (2011) too, identified the key advantage of observation as being able to record data in natural social situations, without having to rely on second-hand sources. They argued that this added validity and authenticity to research findings by providing the rich descriptions needed to understand the situations. Another advantage given was that what people say does not necessarily represent what they do or think, and direct observation provides a means of verifying what might have been recorded in questionnaires or interviews. Concerning NOS, Abd-El-Khalick (2005) only considered this to be taught explicitly if teachers were observed using NOS concepts in class, finding he could not rely on their lesson plans or prior intentions.

However, classroom observation does not guarantee perfectly reliable data. Cohen et al. (2011) also pointed out some of the problems associated with observations, including reliance on interpretations made by the observer, selective recording of evidence and the possibility of missing key aspects due to the complexity of the situation. These factors were mitigated by making an audio recording and checking any interpretations made with the teachers or students in subsequent interviews. The same problems were noted in research on engagement, with questions being raised regarding researchers' ability to categorise whether students were emotionally or cognitively engaged during classroom observations (Fredericks et al., 2004). These issues were discussed more fully in Section 3.2.2. To check my interpretations of events in the classrooms observed I followed these up with interviews of both the teachers and students involved, a vital form of triangulation.

One way of reducing the risk of making preconceived inferences was to adopt a very open semi-structured observational approach. Cohen et al. (2011) suggested this as a useful method of collecting data from which to generate hypotheses, rather than looking for events that support existing hypotheses. To that end I kept a running record of each lesson in my field notes, particularly watching for signs of teachers using NOS concepts, and wrote down comments and reflections as they occurred to me in the lesson. This technique was also recommended by Creswell (2008) as it allows ideas and themes to be developed as the research unfolds. An example of the semi-structured observation protocol can be found in Appendix C. The comments made in the classes were sources of further reflection when listening to and transcribing the audio recordings and were used as stimulus material to explore teacher and student perceptions during subsequent interviews.

Field researchers making observations can take on a range of roles from complete participant to complete observer, the whole continuum being well discussed by Gold (1958). Expressed in these terms my role was of observer-as-participant, as I sat at the back of the classroom, clearly separate from the class and teacher. Wragg (1999) pointed out that the mere presence of an extra adult in a classroom can change the dynamics in unpredictable ways, but that this effect can be minimal if students and teachers are used to visitors. This was often the case at this school and science department, as classroom observations were done regularly by various staff, there

were frequent visits by the science technician or other staff looking for equipment, and in some classes an extra adult was already present as a teacher aid.

I aimed to be as unobtrusive as possible during whole class activities, but during practicals or small group activities I circulated around, talking with and questioning groups and individuals about their experiences. Gold (1958) indicated that when the researcher plays their role well the participants feel comfortable, and the results of the observational encounter are more fruitful. I made every effort to act as an observer-researcher during the observations, with any interactions open and non-judgemental. I asked all the teachers in subsequent interviews if they felt my presence had altered their own or the students' behaviour during the lessons. In only one instance did the teacher feel my presence affected their behaviour, by making her a little nervous, and none indicated any change in student behaviour from what they normally expected.

A number of factors were involved in choosing the actual lessons for inclusion in the study. Firstly, the teachers involved had all completed the VNOS-D survey and interview process, had a good understanding of NOS and were committed to trying to improve their delivery of NOS in the classroom. Especially in the first year, when I was working full-time, the lessons had to be at a mutually acceptable time for both myself and the participating teachers. Within these constraints I tried to visit classes where chemistry related content was being taught, as this is my area of expertise and also enabled some comparisons to be made in similar contexts. Considering all the feedback from the first year it was clear that many staff wanted more specific guidance on how to deliver NOS in their classrooms. So in the second year I wrote a set of experiments related to the particle nature of matter, which specifically included ideas for incorporating NOS. Lessons using these materials were chosen for observation, again with the cooperation of the teachers. Details of the actual lessons observed are given in Tables 4.11 and 4.12.

Table 4.11

*Lesson observations carried out in 2013. \* The first observation done and the only lesson with no audio recording.*

Month	Teacher	Topic	Key activity
May*	B1	Elements	Experiment making and testing hydrogen
May	B7	Space	Research for The Milky Way Times
May	B2	Alchemy and chemistry	Discussion of timeline developing ideas on atoms and elements
May	B2	Properties of elements	Student practical observation and teacher demonstration of elements and their properties
Sept	B3	Space	Experiment on heat loss
Oct	P1	Particle Nature of Matter	Experiment dissolving materials in different solvents

Table 4.12

*Lesson observations carried out in 2014. \* Indicate activities written with explicit ideas for teaching NOS concepts.*

Month	Teacher	Topic	Key activity
May	B1	Elements and compounds	Experiments with iron and sulfur*
May	B6	Particle Nature of Matter	Practical challenge to separate sand, iron filings and salt*
May	P2	Sound	Practical demonstrations of sound waves
May	C1	Particle Nature of Matter and NOS	Experiment heating and melting metals*
May	B5	Particle Nature of Matter and NOS	Experiment heating liquids and measuring expansion*
June	B5	Particle Nature of Matter and data analysis	Graphing of data from expansion of liquids experiment*

Following each lesson observation the information from the field notes and audio recording were combined into a summary transcript with my comments and reflections. Merriam (2009) stressed the importance of following this process as soon as possible after the observation, and that the collection and analysis of the data should be done simultaneously. The written record of the observation was in the majority of cases therefore produced within a few days, and given to the teachers concerned to check and add comments if they desired. A set of questions was attached to the lesson write-up which formed the basis for the subsequent interview with each teacher.

#### **4.7.1 Teacher interviews regarding lesson observations**

Each of the lesson observations listed in Tables 4.11 and 4.12 was followed up with an interview with the teacher concerned. Similar techniques were used for interviewing staff as with the other interviews described in sections 4.5 and 4.6.1 for teachers' views on NOS and TOSRA scores respectively. They included use of a semi-structured format (see Appendix D) allowing for changes in direction during the interview, audio recording, and the return of a transcript with comments for member checking. However, these interviews had more potential to cause problems from an ethical point of view, due to the dual nature of my role in the school as both an educational researcher and the Head of the Science Faculty. Etherington (2007) pointed out that researchers need to be very aware of these power differences and be open and transparent about these relationships, with the aim of balancing the needs of both parties. In order to address this issue, I used the approach recommended by the New Zealand Association for Research in Education (2010), that there "should be in all aspects of research a spirit of open enquiry and open discussion" (p. 5) and took every opportunity to discuss the research project with individuals and the science staff as a whole.

The lesson observations were much more detailed than the participating teachers were used to, even though most had received observation reports many times through the normal school appraisal and self-review process. I found the process of reading research around observation, NOS and engagement, combined with audio recordings, gave me much deeper insight into what was actually happening in the classroom

compared to my usual technique as a fellow teacher or Head of Department observing colleagues. This too, could have caused anxiety for the teachers involved as my observations and comments could be perceived as criticisms of their practice. To counter this possibility the whole exercise was presented as an opportunity for professional growth and improvement, with the recognition that we all needed to improve our practice around NOS delivery. My observations and feedback were seen as a form of professional development and the interviews a chance to reflect on practice and develop successful teaching strategies. Evidence for this viewpoint came from both the willingness of teachers to try the experiments I had written in the second year, as shown in Table 4.12, and from comments made during the interviews:

*B1: It was good to get that feedback for me, and just jolt me ... because sometimes it's the easy way ... to still do what you've done [in past lessons] ... and it actually wasn't that difficult to come up with something slightly different.*

*B2: Very rarely has the content of my delivery been critiqued. And that's because there's never been anybody good enough to do it. I doubt whether there would be anybody else within the department that would have your subject knowledge, really. And that's good for me. I need to be challenged. Thank you.*

*P2: Yes, it was quite useful, especially in terms of the nature of science, and you commented on the things where I could add on a bit more, or make the more explicit link between how scientists work, or how science is done, and what we are doing in class. That was pretty useful.*

Both B1 and B2 were extremely competent and experienced teachers, so to have them acknowledge that there were areas for improvement in such a positive manner was a good indication that there were positive relationships and mutual trust. Merriam (2009) described the role of the researcher in this situation as a collaborative-partner, indicating that this often occurs in action research and leads to benefits to both parties. This relationship was also evident from P2's comments, who as a new teacher appreciated the specific feedback I gave him in the written summary of his lesson. This spirit of mutual benefit resulted in some of the interviews being

quite lengthy (ranging from twelve to forty-eight minutes) as questions were raised by both parties to fully explore aspects of the lesson observation.

Finally, as soon as possible after the interview I listened to the audio recording, transcribing key passages and noting comments and reflections. This write-up was then returned to the relevant teacher to check that the transcriptions were accurate and that any comments correctly interpreted or explained their views. In all cases the staff agreed with the interview write-up. The interview summaries and lesson observations were then analysed as described in Chapter 6, and conclusions drawn related to the research questions.

#### **4.7.2 Student interviews regarding lesson observations**

In order to answer all three research questions from the students' perspective it was important to gather data about the way NOS was being delivered in class by interviewing some students from the lessons I had observed. The same techniques and care were used as described in section 4.6.2 for the interviews regarding students' TOSRA results. The need to allow the interview to develop as a dialogue as suggested by Partington (2001), was even more important so that students gave their impressions, understandings and feelings about the lessons without being directed into responses that limited their answers.

Students were chosen as a result of observations made during the lesson. They were often the students that were closest to me where I sat at the back of the class, and I had noted some of their responses to events during the lesson. Other students were chosen due to particular questions they asked or answered during the lesson, which I noted at the time and were picked up by the audio recording. Table 4.13 shows the students interviewed, the limited number from the first year due to time constraints as I was working full-time.

The interviews were held in a quiet office and were kept considerably shorter than the teacher interviews, ranging from nine to nineteen minutes, as I was aware that there was minimal benefit to the student for their involvement. However, all the students participated willingly, and seemed to enjoy the process, possibly because I

made it clear that I valued their opinions and input into the research process. After many of their answers I would respond with phrases such as the following taken from the interview with student R3:

*That's interesting ... that's neat, great ... alright, good .... Hurray, you can explain, that's great ... OK, yeh ... yep, good ... that's been really helpful.*

Table 4.13

*Students interviewed following lesson observations. \* Indicate interviews in 2013.*

<b>Student</b>	<b>Class</b>	<b>Teacher</b>	<b>Lesson</b>
M3*	9M	B2	Alchemy
M4*	9M	B2	Alchemy
H1*	9F	P1	Dissolving
J1	9A	B1	Hydrogen
J3	9A	B1	Hydrogen
R1	9K	B6	Separation challenge
R3	9K	B6	Separation challenge
W3	9M	C1	Melting metals
W4	9M	C1	Melting metals
C1	9C	B5	Expanding liquids
C2	9C	B5	Expanding liquids
Z1	9N	P2	Sound
Z1	9N	P2	Sound

As with all the previous interviews I took notes at the time, supported by an audio recording. As soon as possible after the interview the write-up was completed, including verbatim transcription of most of the conversation and a brief summary of less significant parts. A copy of the interview write-up was given to each student to check and add comments if they wished. All the students agreed that the interview record was accurate and reflected their views concerning the lesson observed. Finally, the interviews were analysed as described in Chapter 6 and the information gained applied to the three research questions.

#### 4.8 Other data sources

In order to formulate answers to my research questions I collected a variety of data to supplement the surveys, interviews and observations already described. This data was used to further check the inferences I made, beyond the member checking and triangulation built into the main research processes. Osborne et al. (2003b) noted the problems associated with trying to gain accurate data on concepts such as students' attitudes towards science from a single source of information. They pointed out the wide variety of methods researchers had used, from interest inventories to subject selections, as well as attitude instruments and interviews. The aim of gathering data from a variety of sources was therefore to add to the validity and reliability of the conclusions.

Extra data gathered included:

- a) Student feedback forms. Many teachers gave their students an opportunity to comment on their experiences in science lessons at the end of each unit or term. A variety of styles of form were used, with one example given in Appendix F. Generally, the feedback consisted of a mixture of limited response items such as:

*This unit was: enjoyable      OK      not very interesting      boring*

and open-ended responses to items such as: *A comment I would like to make is.* The student responses were anonymous and provided evidence as to whether they were engaged with science or not, and what teaching strategies or activities they enjoyed.

- b) Information on student subject choices at the school over the years prior to, and during the research. While not specifically related to the research questions concerning Year 9 students, this data did provide information regarding attitudes and engagement as a result of changes to the junior science programme. This data was particularly relevant to students choosing senior science subjects in 2013 – 2016, following the introduction of the new curriculum with a NOS component in 2010.

c) Examination results from Year 11 Science and Year 13 Physics students from 2013 – 2015. As with the subject choice data, the results from national examinations did not provide information specifically about the engagement of Year 9 students with their science lessons. However, both teachers and students are judged on these examination results, so it was vital to see if the introduction of NOS into the Year 9 and 10 programmes had any effect on student performance in their subsequent examinations.

The use of information from these extra data sources is discussed in Section 6.3, and the relevance of these to the whole research project explained in Chapter 7.

#### **4.9 Quality Standards**

A useful set of criteria that enabled the credibility and quality of research in the constructivist paradigm to be evaluated was outlined by Guba (1989). Several steps were recommended to ensure credibility and these were followed in the current research project. They included: prolonged engagement (the study ran over three years); persistent observation (sufficient observations were done to allow for valid interpretations); and progressive subjectivity (I continually reflected upon my own viewpoints and discussed these with my colleagues). Creswell (2007) supported these techniques, adding that as well as significant time in the field and extensive data, the collection of the data must be done thoroughly and with sound protocols using multiple sources. However, the key requirement for credibility described by Guba was that of *member checking*, where the researcher has some way of checking with the participants that their interpretations of situations was correct. Polkinghorne (2007) too, agreed that an iterative process of checking interpretations with participants was vital for validation of narrative research. This was achieved by giving all teachers and students who were interviewed or observed written copies of any field notes or transcripts followed by discussions with them to ensure the validity of any interpretations.

Some of the major criticisms of research in the interpretive paradigm relate to its subjectivity and narrowness of focus (Cohen et al., 2011). Can the detailed observations of researchers, who openly acknowledge change in themselves as a

result of these observations, be regarded as valid or reliable? One way of addressing this problem is by triangulation, which Mathison (1988) described as a way of overcoming personal bias, through three different approaches; data, methodological and investigator triangulation. Data triangulation requires the researcher to use several different sources of data, preferably collected at different points in time and space. In this study many different people provided data, and the data was collected over an extended period in different classrooms. Methodological triangulation was a strong feature of this mixed methods research project, using both quantitative and qualitative methods, with the latter including interviews and observations to give further credibility to the interpretations. A good example of this technique is provided in Section 5.3.2.2, where the reasons for decreases in TOSRA scores for Enjoyment of Science were probed through interviews of both the teacher and students involved. Although the qualitative data from this triangulation did support the simplistic quantitative raw score, they also provided more complex explanations, which on the surface could appear contradictory. For example, a decline in TOSRA score could be due to factors unrelated to NOS, such as the relationship between students, or between student and teacher.

Investigator triangulation was the third type identified by Mathison, where more than one researcher is involved so that different viewpoints or conclusions can be challenged within the research team. This was a problem in the current research, where only one researcher was directly involved in data collection. To mitigate this, regular presentations of the methodology and research findings were made to the staff at the school in the study, and to the science education research community at conferences throughout the whole project.

The great strength of triangulation noted by Mathison (1988), was not so much its elimination of researcher bias, but that it provided a wealth of evidence to allow researchers to construct good explanations for the phenomena they are studying. A good example of this in the current research was using the TOSRA data to identify students who apparently had large changes in their attitudes towards science, followed by interviews with them and their teachers. These interviews often revealed more complex reasons for attitude shifts than simply a dissatisfaction with science,

such as the relationships between student and teacher and with other students in the class.

The need for widely accepted quality standards in qualitative research was strongly argued for by Denzin (2008). He pointed out that there has been a social and political trend in recent years from funding agencies and governments, demanding greater accountability and audits of performance built on Scientifically Based Research (SBR). Denzin referred back to the paradigm wars of the 1980s when arguments raged over the merits of quantitative versus qualitative methods, and suggested that rather than returning to those days, researchers should be open to discuss and critique a range of paradigms and methodologies. The aim should be to produce research work that convinces the reader, whether a scholar, teacher or politician, that the conclusions are valid. One response to this call to ensure qualitative research achieves a high level of credibility and acceptance was provided by Tracey (2010). She produced a list of eight criteria which could guide the 21<sup>st</sup> century researcher to produce high quality work. Table 4.14 lists these criteria and provides examples of how the current research aimed to meet them.

Tracey argued that having specific criteria helped both teachers and students of qualitative research by making explicit the core values and best practices of the tradition. This in turn enabled the production of high quality work which satisfies funding agencies and end users of the work, that it is credible and worthwhile. That has certainly been the aim of this research project.

Table 4.14

*Eight criteria for excellent qualitative research as applied to this research project, as adapted from Tracey (2010).*

<b>Criteria for Quality</b>	<b>Various means of achieving quality research with examples from the current project</b>
Worthy topic	Investigating the link between NOS and engagement is timely and significant as countries all around the world are including NOS in their science curricula with the aim of increasing the engagement of students with science.
Rich rigor	This study uses appropriate and complex constructs related to NOS and engagement. A significant quantity of data was collected over an extended period in a careful well thought out manner, then analysed using sound, well-established techniques.
Sincerity	The views and values of the researcher have been clearly described, and challenges faced both ethically and methodologically have been openly discussed.
Credibility	Rich descriptions from many data sources are supported by triangulation and member checking.
Resonance	The aim has been to make the descriptions and conclusions from this very specific case study cause readers to feel sufficient empathy and understanding that they can see its transferability to their own situation.
Significant contribution	The significance will be judged by others, but the aim has been to produce work that is both theoretically and practically significant. It aims to connect NOS with engagement theory, a link with little empirical research, and provides some concrete examples of strategies that work in the classroom.

Table 4.14 continued

*Eight criteria for excellent qualitative research as applied to this research project.*

*Adapted from Tracey (2010).*

<b>Criteria for Quality</b>	<b>Various means of achieving quality research with examples from the current project</b>
Ethical	The research has followed sound ethical procedures at all times, with a particular emphasis on relational ethics as I worked alongside staff and students at my own school. Strong, trusting relationships were vital to collecting honest responses from the participants in order to make the data credible.
Meaningful coherence	This study aims to link NOS and engagement theory with classroom practice. The success of this will again be judged by others, but the research questions, supporting literature, methodology and findings all aim to provide meaning that can be used to improve both students' understanding of NOS and engagement with science.

#### **4.10 Ethical considerations**

I have endeavored to apply ethical considerations to all aspects of this educational research, not just to satisfy regulatory requirements, but also to ensure that the work is of high quality and the key of values of respect, research merit and integrity, justice, and beneficence were met (NHMRC, 2007). Where there is a strong trusting relationship between the researcher and participants then not only is the research more likely to adhere to these values, but the data collected and conclusions drawn will stand up to scrutiny as being valid and reliable. In this research project and school, good relationships already existed between myself, the staff and students. Through the ethically based research process I believe that these relationships have deepened and developed as mutually beneficial research results and insights emerged.

#### **4.11 Chapter summary**

This research project was grounded in the interpretivist paradigm which Treagust, Won, and Reinders (2014) described as a philosophy where “people construct their understanding based on their experiences, culture, and context” (p. 7). In order to understand the effects of teaching with a NOS perspective on the engagement of Year 9 students I therefore had to immerse myself in the world of the teachers and students and interpret the events occurring in the complex context of the science classroom. The case study methodology used was consistent with the interpretivist paradigm and as Treagust et al. (2014) noted, generally requires a considerable amount of qualitative data in the form of interviews and observations in order to build up the rich descriptions necessary to convince others of the validity of the findings.

A mixed methods approach to data collection was taken which Greene (2008) acknowledged as a pragmatic and often creative approach, that has been successfully used in highly practical fields such as education and nursing. The key is to choose methods that will lead to data that best answers the research questions, and to integrate the methods so that they support each other both at the time of the collection and during analysis. Evidence for this approach can be seen in the way I used the quantitative data from the TOSRA surveys to guide the selection of students for interview, and to create specific interview questions for teachers and students. The data from all sources still has to be interpreted by the researcher, but as Greene (2008) stated; “Better understanding of the multifaceted and complex character of social phenomena can be obtained from the use of multiple approaches and ways of knowing” (p.20).

During all stages of the research, information, reflections and preliminary conclusions were discussed with the teachers involved, a process typical of action research. Hendricks (2006) described a key characteristic of action research as collaboration between the participants to collect data from a variety of sources with the aim of improving practice. She also noted that often neither the context nor the participants are controlled, but rather are a result of the researcher’s situation, and so are studied in order to answer research questions. These were all features of my

research as I worked collaboratively with science teachers to improve their understanding of NOS through guided reflection using the VNOS survey and interviews, and improve their teaching practise through observations and feedback.

The question of how much data to collect in order to answer the research questions was noted by Merriam (2009) who stated, “Ideally, depletion of resources coincides with saturation of information” (p. 123). This was certainly the case with my research, with time being the limiting resource, and a wealth of material having been collected over the two-year period of active research. Merriam (2009) also pointed out that qualitative researchers must acknowledge the subjective nature of their interpretations, and check these by regularly sharing these and their conclusions with the participants and other interested parties. As a novice researcher I was particularly aware of the need to do this, and also felt that my findings had immediate value to the staff involved, so was particularly keen to share the information. To this end I regularly summarised my research and presented it back to the science staff at meetings throughout the research period, encouraging staff to make criticisms and comments, a process Lincoln and Guba (1986) called peer debriefing.

The data collected as result of the methodology described, is presented and analysed in the next two chapters. Chapter 5 deals with the both the VNOS and TOSRA surveys and interviews, while Chapter 6 focuses primarily on the lesson observations, with a short section on the other forms of data collected. Finally in Chapter 7, the research questions are addressed using all the information available, with recommendations made, and the limitations of the research discussed.

## **CHAPTER 5 Results and discussion related to VNOS and TOSRA data**

### **5.1 Introduction**

The data collected through the various methods described in Chapter 4 consisted of four types:

1. Written responses and interview data from the VNOS survey of staff.
2. Quantitative data from the TOSRA survey of Year 9 students, supported by interviews with students and teachers concerning this data.
3. Lesson observations, with subsequent interviews of the students and teachers from those lessons.
4. A variety of other data, including: student feedback forms; examination results; and subject choice information.

The first two sets of data are analysed in Sections 5.2 and 5.3 of this Chapter, while the last two categories are the focus of Chapter 6. The results and discussion are presented with the aim of addressing the research questions, as stated in Section 1.4, and the overall purpose of this thesis: to investigate the effectiveness of teaching with a NOS approach on the engagement of Year 9 science students.

As with the process of research in science itself and acknowledged as a key theme in NOS (Osborne et al., 2003a), neither the sequence outlined in the method nor the analysis of the data was linear, although they are presented in this chapter as a series of ordered steps. The reality was that each stage overlapped with the others, and insights from one set of data was immediately used to inform teaching practice, as is typical with an action research approach in a case study setting (Cohen et al., 2011). So, for example, as teachers gained deeper understanding of NOS ideas through the VNOS surveys and interviews, these were shared and discussed at Science Faculty meetings, with the expectation that teachers would share their improved NOS knowledge with students in their classes.

Thus, professional development for staff took place throughout the research, including before and after the actual data presented here was collected. For example, while carrying out the literature review I would circulate key findings and discuss

ideas both formally and informally with staff. After each major set of data was analysed I would prepare a presentation for various science conferences summarising the research so far, and these would also be presented to the staff for discussion and constructive criticism. As new staff arrived at the school they were invited to participate in the project, initially completing the VNOS survey, and then trialling material developed to deliver NOS such as the experiments for the Reactions Matter Unit in Year 9. Thus the data and analysis presented in Chapters 5 and 6 must be viewed from the perspective that the research itself was intended to cause changes in the understanding of NOS for the staff, and in the delivery of NOS in their classrooms.

## **5.2 Teachers' views of nature of science**

The written answers and interview responses to the VNOS surveys provided a wealth of information related to several of the research questions, especially as they were spread across several years. The intent was to establish what the teachers' views about NOS were, and then see if these were reflected in their teaching practice. However, as described in Chapter 4, the interviews revealed more than simply the teachers' understanding of NOS concepts – providing information about the use of NOS in their classes and their perceptions of its effectiveness in engaging students.

### **5.2.1 VNOS Teacher surveys**

Teacher responses to the VNOS questions varied considerably, from brief hand-written notes to extensive, paragraph-length typed responses which included examples illustrating key points. The data indicated that all the teachers had a good understanding of NOS concepts, although the degree to which this could be deduced varied according to the extent of the written answers given. Responses were analysed in relation to the ten NOS themes drawn from the literature as summarised in Table 2.1. This involved identifying key words for each theme, counting the number of these in each teacher's responses, then reading and re-reading their answers to make a judgement on their degree of NOS understanding. These judgements ranged from naive to sophisticated, as described more fully in Section 4.4.1.

### 5.2.1.1 Tentative NOS

The sophisticated view: Scientific knowledge is tentative but stable. Theories are supported by evidence but subject to challenge and change.

All the teachers were very clear that science ideas were subject to change, most mentioning this several times in their responses and providing unequivocal written answers. The responses from a sample of the teachers who had their lessons observed are shown in Table 5.1.

Table 5.1

*Sample of written responses from the VNOS surveys related to the tentative NOS.*

Teacher	Use of words related to change	Response that illustrates viewpoint	Naïve/Transitional/Sophisticated
B1	5	Science is ever changing; we only need to look at human history and the scientific explanations of the time to be able to extrapolate that some of the ideas and ‘theories’ that are currently held could be changed in some way.	Sophisticated
B3	5	As new developments brought to light or discoveries made the current theory can change.	Sophisticated
B5	1	Theories are modified as we gather more evidence & understanding of how it works.	Sophisticated but limited evidence
P1	4	As more evidence is found a theory will change, sometimes as an evolution, sometimes as a revolution.	Sophisticated

The numerical value given refers to counts of words related to change (change, tentative, modified, disproved) taken in the context of their answers.

Although several teachers only made limited use of these specific words, their intent was very clear, and many used good examples to illustrate the tentative NOS. Teacher B5 was the only one without a clear example of a theory that had changed, which reinforced the need to interview people in order to explore their views of NOS more fully.

### **5.2.1.2 Empirically based NOS**

The sophisticated view: Science is based on observation and data but dependant on the instruments and methods of data collection.

All the teachers expressed clearly the view that scientific theories and explanations have to be based on sound evidence. In their examples they consistently referred to improved technology being responsible for modifying theories as new evidence became available. For example, B1, who used the word ‘evidence’ 22 times, also stated that:

*It takes someone with great imagination to build the right equipment to enable a scientists to come up with answers, take the hadron collider, or a lot of the tools used in current biotechnology such as PCR.*

Many teachers linked the use of new technology to collect observations with the tentative NOS, recognising that the new evidence generated often requires new explanations, as shown in Table 5.2. Two teachers (B5 and P2) only used the term ‘evidence’ three times in their written responses, but clearly understood that science is based on empirical evidence using the terms ‘observation’ or ‘data’ in this context on eight (P2) and thirteen (B5) occasions. Again the interview process allowed for clarification and assessment of their level of understanding.

Table 5.2

*Sample of written responses from the VNOS surveys related to the empirical NOS.*

Teacher	Use of the word 'evidence'	Response that illustrates viewpoint	Naïve/Transitional/ Sophisticated
B2	7	Science endeavours to explain 'stuff' through careful observation and analysis of phenomena and events.	Sophisticated
B6	13	Scientists are constantly searching for evidence to prove (or disprove) current knowledge.	Sophisticated
B7	13	As science and technology evolves – new evidence can come to light – changing or enhancing our knowledge	Sophisticated
P1	7	When Galileo found new evidence about the planets it changed the theory of how our solar system worked.	Sophisticated
P2	3	The level of certainty [in a theory] would be proportional to the quality and quantity of the scientific evidence they have gathered and studied.	Sophisticated
C1	5	The development of new technology allows for new observations to be made.	Sophisticated

### 5.2.1.3 Scientific method and critical testing

Sophisticated view: There are many ways of answering scientific questions, but methods must be sound, repeatable and subject to peer review.

The VNOS survey did not appear to be a good tool for eliciting teachers' views concerning this aspect of NOS, as can be seen from Table 5.3. The survey questions did not prompt teachers to explain their views of the scientific method in detail, although looking at the answers holistically, the naïve view of science – that it follows a rigid procedure – was not evident. As there was little information to form a judgement on the degree of understanding of this aspect of NOS (hence 'insufficient evidence' in Table 5.3), the interview data became crucial. However, one teacher (P3) did give a comprehensive answer to question one, 'What is science?', which clearly demonstrated a sophisticated appreciation of the methods of science:

*For me, Science is simply the rational explanation of the world we live in. By rational explanation I mean observation-based evidence which supports an idea or hypothesis. This includes experimenting, fair testing, research, logical thought processes, critical analysis and honest reflection, and verifiable/repeatable results which hold up to peer review. It is not necessarily a linear process (as often taught) and can sometimes be driven simply by luck or circumstance.*

This high level of understanding regarding NOS given by P3 prompted me to invite him to share his views on NOS and wider experiences in science with the whole Science Faculty. This is a good example of the way in which information from the research was used to improve the NOS knowledge of all the science teachers as the project unfolded.

Table 5.3

*Sample of written responses from the VNOS surveys related to the methods of science.*

Teacher	Use of the words 'peer' or 'critic'	Response that illustrates viewpoint	Naïve/Transitional/Sophisticated
B1	0	Science is about investigating phenomenon, hypothesizing, generating theories and explanations for the natural world.	Insufficient evidence
B2	1	It [science] involves the explanation, manipulation and discussion using data from observations and scientific knowledge. ... The biggest critics are also Scientists!!	Insufficient evidence
B5	2	It involves asking a question, forming a hypothesis and testing the hypothesis by gathering observations, and finally drawing conclusions based on the data gathered. Scientists need to have sound peer-reviewed data that is open to critique and questioning.	Sophisticated, but limited evidence
P2	0	Science is an endless and continuous process of investigating, forming/creating and evolving ideas and theories.	Insufficient evidence
C1	0	Scientific knowledge is based on observations and using these to theorise what is happening	Insufficient evidence

#### 5.2.1.4 Subjective/theory laden NOS

Sophisticated view: Scientists' background, prior knowledge and theories, influence what, how and why investigations are carried out.

Once again, the questions in the VNOS survey did not prompt the teachers to clearly state their views on this aspect of NOS. There were no obvious key words to search for and generally there was only one phrase or comment that could be related to the idea that a scientist's background may influence their thinking. Therefore, no judgement was made on their degree of sophistication concerning this NOS theme, as the evidence was slim. However, the responses shown in Table 5.4 did as a whole indicate that the teachers have an appreciation that scientists are influenced by their experiences and prior knowledge.

Table 5.4

*Sample of written responses from the VNOS surveys related to the subjective/theory laden NOS.*

Teacher	Response that illustrates viewpoint
B1	There may be reasons for the different beliefs – are there other influences on the scientist and the evidence they are looking at?
B2	Scientists use their own experience of the world around them to model scientific theories.
B3	Interpretation of models is subjective and again open to personal interpretation based on models and historical precedents
B6	The lack in (total) evidence allows a degree of interpretation and such is human nature, everyone can interpret the same information differently
P2	Scientists or no scientists, people are very diverse in terms of the way of thinking.
C1	One scientist may place more importance on one piece of evidence where as another scientist might not think the same piece of evidence is very important.

### **5.2.1.5 Creativity and imagination**

Sophisticated view: Science is highly creative/imaginative in many areas: formulating ideas/hypotheses, experiment design and communication of findings.

Question seven in the VNOS survey specifically asked about creativity and imagination in science and so all the teachers mentioned these factors in their responses, as shown in Table 5.5. All agreed that creativity and imagination were crucial in science, with only B2 limiting her answer to science as related to technology. However, B2's written answers were all brief, so this aspect was probed further during the follow-up interview. The only teacher to mention creativity in response to a question other than number seven was P2, who offered this response to Question Two, "What makes science different from other subjects/disciplines?"

*Science is an endless and continuous process of investigating, forming/creating and evolving ideas and theories.*

These firm views on creativity and science shown by P2 were confirmed in the interview and evident in his classroom practice (see Section 6.2.7) where he demonstrated a creative and iterative approach to help his students explain the science behind sound.

### **5.2.1.6 Socially/culturally embedded NOS**

Sophisticated view: Science influences and shapes society and culture, and *vice versa*.

Question ten in the VNOS survey specifically targeted this aspect of NOS, and generated the widest range of responses, in terms of the length of the answers, to any of the survey questions. However, as shown in Table 5.6, most teachers described only one side of the relationship, arguing either that science influences society, or that society and culture influence science. These views were labelled as transitional, with the alternative view posed as a question in the subsequent interview. Once

Table 5.5

*Sample of written responses from the VNOS surveys related to creativity and imagination in NOS.*

Teacher	Use of the words 'creative' or 'imaginative'	Response that illustrates viewpoint	Naïve/Transitional/ Sophisticated
B1	4	It takes imagination to look at your observations and try and explain why does that occur.	Sophisticated
B2	2	Creativity is wonderful in the use of science for technology advancement.	Transitional
B3	2	Creative solutions may obtained by looking at an old problem in a new way.	Sophisticated
B5	2	Scientists need to be creative in their approach to finding answers	Sophisticated
B7	2	Creativity is also important for seeing/finding a problem and then the solution.	Sophisticated
P1	5	I believe that scientists use their imagination and creativity in ALL parts of investigations.	Sophisticated
P2	3	Planning and testing experiments are both open to creativity.	Sophisticated
C1	3	I think there is a lot of imagination and creativity in the planning of an investigation. People have to be creative to figure out how to answer their questions.	Sophisticated

Table 5.6

*Sample of written responses from the VNOS surveys related to the socially/culturally embedded NOS.*

Teacher	Use of the word 'society' or 'culture'	Response that illustrates viewpoint	Naïve/Transitional/Sophisticated
B1	5	I think the nature of science explicitly tries to bring about the relationship between Science and Society, and we can see this in our current NZ curriculum, which includes things like participating and contributing which looks at socioscientific issues.	Sophisticated
B2	1	Many communities actively avoid some scientific theories because it (sic) does not culturally fit.	Transitional
B3	3	Cultural values change from place to place and time to time. Science may prove a current belief system to be wrong but if it is not taken up by the majority of the populace then it is not accepted as fact.	Transitional
B5	2	The Age of Enlightenment has had a huge influence on culture, influencing the course of Western history.	Transitional
P1	2	Science drives the development of technology, and technology shapes cultural values.	Transitional

again, P3 provided an answer which demonstrated plenty of prior thinking on the topic and a sophisticated understanding of NOS:

Q10: Is there a relationship between science, society, and cultural values?

P3: *Yes, huge! Both positively and negatively. Starting with caveman experimenting with adzes, flints, fire and the wheel advancing through to the Romans, a decline in Science, knowledge and culture in the Dark Ages, and re-awakened during the Renaissance with Scientists and Artists such as da Vinci, through to the industrial revolution and the quantum and subsequent computer revolution. In terms of quantifying the relationship – I would say that society and culture advances as science advances, and vice versa.*

#### **5.2.1.7 Observation v inference**

Sophisticated view: Recognises that it is possible for different scientists to legitimately come to different conclusions based on the same data.

All the teachers made at least one clear statement indicating they appreciated that scientists could interpret evidence differently, as shown in Table 5.7. As with the results for their views on the empirical NOS, the idea that scientists can make different inferences or conclusions based on the same data was strongly linked to the tentative NOS by many of the teachers. If different interpretations are possible then the original explanations offered for observed phenomena must be open to change, either in response to more convincing arguments using the same evidence or when new evidence comes to light. For example, B7 stated:

*Science is different because it is based on ideas/hypotheses that need to be tested/observed and then at time modified or changed – even thrown out if proven wrong.*

Table 5.7

*Sample of written responses from the VNOS surveys related to observation v inference.*

Teacher	Number of references to the concept	Response that illustrates viewpoint	Naïve/Transitional/Sophisticated
B1	3	There are different ways of looking at the same evidence and the puzzle pieces may still fit but have a slightly different picture.	Sophisticated
B3	3	Not all people interpret information in the same manner. Also the evidence that is present may be in complete or not completely understood by all.	Sophisticated
B5	2	The model of the Earth's inner layers is inferred, but it is based on real observations.	Sophisticated
B6	3	The lack in (total) evidence allows a degree of interpretation and such is human nature, everyone can interpret the same information differently.	Sophisticated
P1	6	An observation will not change but the interpretation of this observation may	Sophisticated
P2	3	Scientists disagree because they are able to interpret and analyse information differently from each other.	Sophisticated
C1	2	Their information could be interpreted differently by different scientists	Sophisticated

### 5.2.1.8 Theories v laws

Sophisticated view: Different kinds of knowledge. Laws are descriptive statements of observations and theories attempt to explain phenomena.

Question eight in the VNOS survey specifically asked about the difference between theories and laws. As shown in Table 5.8, the majority of teachers demonstrated a good understanding of these differences, with several responses bearing a striking similarity to the definitions offered by Lederman (2007, p. 833): “Laws are statements or descriptions of the relationships among observable phenomena. ... Theories by contrast, are inferred explanations for observable phenomena.”

I was surprised at the time at the degree of sophistication of the teachers’ understanding relating to theories and laws, as this has been an aspect of NOS identified as being particularly weak in the literature. Lederman (2007) referred to several previous studies that found students and teachers had naïve views, such as laws represent the truth, and that theories become laws after sufficient testing. Lederman argued that if people had a good understanding of the differences between theories and laws they should also have a good grasp of several other NOS themes, such as the importance of new observations, re-interpreting and critiquing evidence, and the subsequent tentativeness of scientific ideas. Allchin (2011) however, argued that being able to distinguish between theories and laws was perhaps the least important aspect of NOS, stating that what really mattered was to be able to evaluate the worth of a claim, based on the evidence. Given the common use of the terms ‘theories and laws’ in text books and curriculum documents, Abd-El-Khalick (2012) argued that it was important for teachers to have a good understanding of them in order to help students to see their central role in science. Given the discussion in the literature I felt it to be particularly important to probe the teachers’ understanding concerning theories and laws in the subsequent interviews.

Table 5.8

*Sample of written responses from the VNOS surveys related to theories v laws*

Teacher	Response that illustrate viewpoint	Naïve/Transitional/ Sophisticated
B2	... scientific law can be modelled and tends to be bound by mathematical formula. Theory, less evidence, possibly due to more variables, still in the process of developing.	Transitional
B5	I see a Law as being a fact within a field of science (usually with a mathematical component e.g. Newton's Laws of Motion). I see a scientific theory as a collaboration of different fields within science coming together to explain a phenomenon ... It is a sound peer-reviewed process.	Transitional
B6	A theory is essentially a hypothesis that has had some results to support it and is yet to be shown to be wrong. A law is more based solely on observations with many facts that support it. It is less likely to explain 'why' something happens.	Sophisticated
B7	A law is descriptive – it describes something that has been observed. A theory – explaining an observation. Stating why it might be like that.	Sophisticated
C1	A scientific law describes what is happening based on observations. A theory tries to explain what is happening. The theory of evolution explains why there is such a diversity of life on earth.	Sophisticated

### **5.2.1.9 Argumentation**

Sophisticated view: Can justify views on NOS through sound reasoning with a strong grasp of practice. Scientific claims are negotiated and verified through argument within the relevant science community.

As with the NOS theme concerning theories and laws, having an appreciation of the role of argument and debate in science requires a good understanding of several other NOS themes, and therefore is a good indicator of the overall level of sophistication a person has concerning NOS. While questioning and holding an argument are traits more easily tested in an interview situation, the teachers provided many examples of the need for argumentation in science, as shown in Table 5.9. The importance of teachers seeing argumentation as a key part of NOS was highlighted by Deng et al. (2011), who noted in their summary of over 100 interventions to improve students' NOS knowledge that, "effective interventions generally involve inquiry, discussion, reflection and/or argumentation activities" (p. 979). So it was particularly important to establish the teachers' views of NOS concerning argumentation, in order to see how this affected their ability to incorporate NOS into their classroom practice.

### **5.2.1.10 Cooperation and collaboration**

Sophisticated view: Scientists work collaboratively to develop new ideas. They cooperate in order to carry out practical research and to share and critique the knowledge produced.

As described in Chapter 4, this NOS theme was only added after the lesson observations were completed. This meant the analysis of teacher responses to the VNOS surveys concerning cooperation and collaboration was done at the end of the research rather than at the beginning, when all the other themes were analysed. The VNOS survey itself did not specifically probe this aspect of NOS, but recognition of the importance of cooperation and collaboration did emerge in responses to a number of the questions. For example, teacher B5 responded to Question eight, about theories and laws by stating:

Table 5.9

*Sample of written responses from the VNOS surveys related to argumentation.*

Teacher	Reference to an 'argument'	Response that illustrates viewpoint	Naïve/Transitional/ Sophisticated
B1	6	Evolution is another heated argument around the idea whether it occurred or not. With the onset of genome analysis, the mapping of the human genome which shows how similar organisms are, the evidence now is very powerful	Sophisticated
B2	3	[Science] involves the explanation, manipulation and discussion using data from observations and scientific knowledge	Sophisticated
B3	3	Present an argument that can be substantiated with the most recent data on all points of concern.	Sophisticated
B5	2	Scientists need to have sound peer-reviewed data that is open to critique and questioning.	Sophisticated
B7	2	As technology and knowledge is shared more information is unveiled – either supporting or disproving the original theory.	Limited evidence
C1	3	If someone makes a scientific claim they should have something to back it up ... Explain ALL of the evidence, have more than one piece of info to back up the theory.	Sophisticated

*I see a scientific theory as a collaboration of different fields within science coming together to explain a phenomenon.*

Teacher P2 clearly saw collaboration as central to the way science works, as shown in his answer to Question one:

*Science is also (ultimately) a collaboration of every scientific mind in the world.*

Although none of the other teachers who completed the VNOS survey specifically used the words cooperation or collaboration, they all recognised that scientists need to work with others. Teacher C3 put this clearly when he described the work of a local leader in cancer research:

*The big point he makes in his research is that it is the group he works with that gives his research the edge.*

Other teachers described the importance of critical feedback to scientists through peer review of published work, or mentioned that theories may be developed by one person, but tested by teams of other scientists. Another common theme that emerged in the final question about science and society, was that scientists have to work with many different groups of people, often simply to secure funding for their work. So although there was insufficient evidence to characterise every teacher's NOS understanding as naïve or sophisticated it was clear that as a group they did recognise that scientists must cooperate and collaborate with others.

#### **5.2.1.11 Summary of VNOS-D Analysis**

The written responses to the VNOS-D survey are summarised in Table 5.10, for the nine teachers who were subsequently observed, and shows a high degree of sophistication among the teachers' concerning their knowledge about NOS. Given that three of the NOS themes were not specifically targeted in the questionnaire, the teachers still showed a good overall understanding. Taking a holistic view of each person's responses, there were certainly none with naïve views of NOS. However,

the judgements were based on the limited evidence presented in some of the written answers, hence the need for more data from the interviews.

Table 5.10

*Summary of NOS understanding based on responses to the VNOS-D instrument, for teachers who were subsequently observed. Numbers refer to the ten NOS themes.*

Teacher	Degree of NOS understanding		
	Transitional	Sophisticated	Insufficient evidence
B1	0	7	3
B2	2	4	4
B3	1	4	5
B5	2	6	2
B6	0	5	5
B7	0	6	4
P1	1	6	3
P2	1	6	3
C1	1	6	3

### 5.2.2 Teacher interviews concerning their views of NOS

The use of interviews to validate the VNOS questionnaire was comprehensively discussed by Lederman et al. (2002) who provided examples of responses that illustrated the range from naive to more informed views of NOS. Lederman et al. also provided examples of useful questions to probe the participants' understanding and many of these were used in this project, as described in Section 4.5. The prime purpose of the interviews was to establish the depth and consistency, or degree of sophistication, of NOS understanding for each teacher across the whole range of NOS themes, which may have been difficult to evaluate, or were missing, from their written responses to the VNOS-D survey. In Section 5.2.2.1 the analysis of the interview data focuses firstly on the NOS themes with limited evidence from the written survey. Then in Section 5.2.2.2 the focus is on the responses of teacher B2, as she had the lowest level of NOS understanding, as revealed by the VNOS-D questionnaire.

### 5.2.2.1 Interview evidence to supplement VNOS-D responses

The first NOS theme that produced limited evidence from the VNOS-D concerned the methods of science. After reviewing the interview transcripts and re-listening to the recordings it was clear that all the teachers did understand the need for results to be repeatable and to be critiqued by other scientists. The following quote typifies the level of understanding:

*B1: The whole system is out there to put something out, to carry out some experiments, whatever ...and then you need to have that peer-reviewed ... so someone else needs to be able to replicate it.*

Another NOS theme generating limited evidence from written responses concerned the subjective/theory laden NOS. The following extract from the interview with P1 is typical of the type of discussion I had with all the teachers on this issue, which always began with the same question:

*Interviewer: It is very reasonable to say that data is scarce and that the available data could support several hypotheses equally well. However, scientists supporting the different hypotheses are very adamant about their own position and often publish very pointed papers in this regard. Why is that?*

*P1: I suppose ultimately people think that they're right ... so they're going to make the arguments that show that they're right.*

*Interviewer: Is it possible for scientists to always be objective when interpreting their findings?*

*P1: I don't think so.*

*Interviewer: Is this a good or bad thing?*

*P1: It's bad if you become set in your ways. You don't remain objective. Because you will become attached to whatever theory you come up with.*

Interviewer: *So how do scientists deal with their own subjectivity then?*

There were long delays in answering throughout this section as P1 thought carefully about his responses.

P1: *One way of dealing with it, would be the repetition. You know, if you get someone else to repeat the experiment, they may bring, they may remove that level of subjectivity, as, ah, that extra objective observer.*

The use of this sort of questioning technique in all the interviews enabled me to both confirm the judgements made on specific NOS themes based on the VONS-D, and my more holistic conclusion that all the teachers had a very good general understanding of NOS. However, it became clear that some teachers had a weaker understanding of some of the nine NOS themes, while showing an integrated, coherent understanding overall. This is well illustrated in the detailed analysis of the views of NOS for teacher B2, as described in the following section.

### **5.2.2.2 Views of NOS for teacher B2**

According to the analysis in Section 5.2.1, and as summarised in Table 5.11, teacher B2 displayed sophisticated views of NOS in four of the NOS themes, transitional understanding in two, with insufficient evidence to make a judgement in a further four.

After my first reading of her responses to the VNOS survey, I noted that B2 wrote fairly brief answers but clearly considered many of them self-evident, needing little explanation, often phrased with a humorous tone. For example, in response to Question four; “How do scientists know that dinosaurs really existed? Explain your answer”, she wrote:

*Fossil evidence.....are you serious Dave!! But I know there isn't a lot of it to help build up the bigger picture.*

Table 5.11

*Teacher B2's degree of NOS understanding as derived from the VNOS-D questionnaire.*

NOS theme	Transitional	Sophisticated	Insufficient evidence
Tentative		✓	
Empirically based		✓	
Scientific method and critical testing			✓
Subjective/theory laden			✓
Creativity and imagination	✓		
Socially/culturally embedded			✓
Observation v inference		✓	
Theories v Laws	✓		
Argumentation		✓	
Cooperation and collaboration			✓

Or in Question nine; “After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example”, she wrote:

*Of course....I've discussed this earlier.*

This lack of argumentation and discussion seemed to indicate a less sophisticated understanding of NOS. However, during the interview, B2 showed much deeper insight and understanding of NOS issues, including reflection on curriculum implementation both in New Zealand and the United Kingdom. B2 identified her period as Head of the Science Faculty in a UK school as the time when she gained most knowledge about NOS.

A new curriculum was introduced which initially required a completely investigative approach to teaching. Full schemes of work and support materials were provided, and these became the source of NOS knowledge for B2:

*Through the curriculum guidance, which was given to me as a head of faculty. .... they made it [NOS] very explicit, how it should be taught.*

However, when putting the curriculum into practice in the classroom she noted:

*We were given an exemplar scheme for junior science, which was entirely an investigative scheme. And that was quite difficult, it didn't work for our students.*

These comments indicated that B2 did have a good understanding, not only of NOS, but of the pedagogical problems involved in teaching NOS.

Returning to specific NOS themes in the interview, B2 linked together the subjective/theory laden NOS with the passion and creativity needed in science:

*I think that sometimes, that there is that element of, I suppose, subjectivity, rather than the objectivity, when you are passionate about something and you believe in it strongly...and I think that does happen with some scientists.*

*I think that combination of creativity and scientific ... or that ability to be scientific is quite unusual, really ... I do think they can sort of, they can work hand-in-hand.*

The NOS theme regarding theories and laws was an area where B2's understanding was categorised as transitional, based on the VNOS survey. When questioned specifically about theories and laws in the interview, and whether one was more significant than the other, she stated:

*No, I don't think so, I think they're both just different. A law is quite explicit, because there are variables that link to each other ... whereas a theory there's just so many variables out there, which could have an influence, it's always going to be further researched and discussed.*

This demonstrated part of the sophisticated view that theories and laws are different kinds of knowledge, but B2 was not able to clearly differentiate theories as explaining phenomena and laws being statements of observations. B2 acknowledged her hesitancy in this area, saying:

*I just don't know enough about it really, and I should be honest about that. I've always considered a scientific law to be very mathematical ... and the variables are quite fixed. Whereas a theory, there's just too many parameters, too many variables.*

I regarded this admission of a lack of knowledge as an indication that the answers B2 provided were genuine, giving me confidence in the validity of the data.

The final two NOS themes for which there was little evidence in B2's VNOS answers concerned the methods of science and the need for cooperation and collaboration. When her ideas around methods were probed during the interview she clearly recognised the need for reliable methods that were open to critique, stating:

*There are very strict procedures for collecting data and looking at its reliability. And also the peer review of data as well.*

The need for discussion and peer review of ideas came up several times, indicating that B2 did understand the importance of cooperation, even if this was in terms of scientists testing out their ideas by presenting and defending them. The notion of a scientific community was also mentioned by B2, for example describing how theories such as the causes of Global warming are built from multiple investigations, discussion and eventual consensus in the community of scientists. She returned to the theme of scientific methodology during our discussion of creativity in science, recognising the need for creativity in generating questions, but noting that rigour was required when analysing the results:

*The creativity can come from thinking about what to investigate. In terms of being objective about your data ... it's just a method of analysing scientific data and checking its reliability. It's very methodical, and you've got to be very, very objective with it.*

These responses showed once again B2's ability to link ideas together and demonstrate consistent views over a range of NOS themes. As Lederman et al. (2002) stated, it is this synthesis of NOS ideas that indicates a person has a deep understanding, rather than a stock response to specific NOS questions. B2 clearly did have a good understanding of NOS, although not covering every theme to equal depth. She also indicated several times the value of teaching about NOS, best summed up in this response to the question; "Why should we teach about theories which have subsequently been replaced?":

*It's exciting [laughter]. I think that's what it is about science, it's about wanting to know about the unknown, and its discovery, and that makes us passionate about what we do. If they're not taught about that, then they won't understand that process itself ... being aware of what's happened and how there've been modifications. It's very exciting.*

So the interview data revealed that B2 did have a good understanding of NOS, even though her written responses were limited. This gave me confidence in the judgements I had made about all the teachers' NOS knowledge, especially as these judgements were confirmed each time I analysed the interview data.

### **5.2.3 Application of VNOS results to the research questions**

The first finding to emerge from the VNOS-D survey and interviews was that all the teachers had a good understanding of NOS (Research Question 3). Previous studies suggested that High School teachers often have naïve views of NOS, or well-developed understanding in some areas but poor understanding in others (Lederman, 2007). Another finding from past research indicated that even though the VNOS process may reveal sound NOS understanding in some teachers, this was not necessarily transferred into classroom practice (Bartos & Lederman, 2014). Thus, the

the VNOS-D instrument can be used to establish teachers' understanding of NOS, but does not provide any information concerning the teachers' approach to delivering NOS in the classroom. Whether or not NOS was being delivered in the classroom, the strategies used and their effectiveness (Research Questions 1, 2 and 3a) was therefore primarily addressed using the TOSRA data and through classroom observations. However, data pertaining to aspects of these questions was collected during the VNOS interviews, and is discussed in Section 5.2.3.1. Similarly, data revealing the perceptions of teachers regarding the effectiveness of NOS to engage students (Research Question 1a), was also gathered during the VNOS interviews, and is discussed in Section 5.2.3.2.

### **5.2.3.1 Teaching strategies for NOS described in VNOS interviews**

A summary of the research on effective strategies for teaching NOS is given in Appendix I. Of the seventeen strategies listed, ten were described as being used in their classes by the teachers during the VNOS interviews. All eighteen of the teachers interviewed gave an example of at least one of these strategies used in their classes. One example of each strategy mentioned is described below:

i) Explicit teaching of NOS ideas and ii) scaffolding

B1 described a strategy designed to support or scaffold thinking around theory-making and how selecting different pieces of evidence can produce different theories:

*When I did introduce my evolutionary theory, and I did use the little tangram puzzle ... I felt the students had a better understanding of what a theory was, rather than in the past, just sort of, talking about it. ... It engaged them and actually [helped their] understanding what it means to be a theory.*

iii) Questioning - focus on justifying explanations through the use of evidence.

C3 indicated that he had changed his teaching and now used a NOS approach when looking at experiments in class:

*I've become a bit of a ... more of a convert. As much as you do an experiment, but rather than telling them what went on, you ask the kids, well what do think went on?*

iv) Visiting scientists – in person or through videos.

When asked about inclusion of NOS in her own teaching, B5 referred to a video clip on using firefly genes to follow drug treatment:

*I think that'd be what'd be really cool. Get more resources like that, you know, where you could play them a few minutes at the start or end [of a lesson] just to sort of, link it with real life opportunities for them.*

B5 then indicated that her students were also interested and engaged during a visit by a microbiologist:

*They were asking questions that were relevant.*

v) Integration of NOS with inquiry in relevant context

Teacher C5 described one activity where students had to design and build a torch given only basic materials:

*In the electricity unit, there was a great lesson I had with my class, the torch challenge ... they had to demonstrate some of those skills that are related to NOS.*

vi) Stories from science

C4 gave an example related to creativity in science and described how he had used his own experiences as an agricultural scientist to illustrate this in his teaching:

*Yeh, I was talking to my science class the other day about that. I guess for us it was ingenuity and creativity at the same time. We were using a trial harvester, which is essentially a combine harvester which has been shrunk.*

vii) Use authentic, context-rich tasks

Teacher B6 described the value of one of the lessons I wrote with NOS ideas made explicit:

*If you just look at that, especially that Chemistry unit with Year 9's that you looked at. Those links, those direct links to the, sort of lesson, to the sort of real world were, sort of great for, me.*

He went on to explain that he felt the students were engaged by recognising the link between their experiment in class and the application of the same ideas to real world problems.

viii) Argumentation/discussion

Several teachers described how they encouraged students to build arguments using the evidence and to question the conclusions made, especially in relation to our model of the structure of the earth (VNOS-D item 6). The excitement of teacher B8 in his first year of teaching, came through strongly during the interview as he described the effects of encouraging questioning and argumentation:

*B8: A lot of them said, how do we know? How do people know that that's what the earth's made of? In fact I was quite surprised at how many wouldn't, didn't take it as law, you know. A lot of them asked, well how do we know that in the middle of the earth is solid?*

*Interviewer: And you say you were surprised, but were you pleased to get those sorts of questions, or were you thrown by it?*

*B8: Pleased and thrown. I was thrown because you're doing your thing and wow, that's really, really, you know, inquisitive of that student. Yeh, I was pleased as well though, you know, wow, they actually do want to know how we know these things. What have people done so that we have this information. And, you know, that shows that they are thinking.*

viii) Create a supportive classroom environment

While discussing the way she encouraged students to question the models and theories proposed in science, teacher P4 went onto to comment on the care needed in the classroom:

*You don't want to cause offence. And you don't want to actually cause such problems that their whole cultural belief system falls apart without any support structures.*

ix) Open-ended questions and x) Publishing inquiry work beyond the classroom

Several teachers referred to the School Science Fair as providing opportunities for students to ask and answer their own questions, as well as requiring them to present their findings to a wider audience. Teacher B3 explained why he valued the Science Fair approach as a teaching strategy:

*I think it [science] needs to be hands-on ... to get in and do things. So, for me it's all about getting in there and doing stuff. And if you ask the kids, I don't think any of them will say, I want to do more writing, it's usually more experiments, explosions, dissections. And they do want to find out things ... and it's just kind of fostering that wonder, that exploratory nature, that I think all kids have.*

Thus the data from the interviews showed that all the teachers were aware of, and used, a variety of recognised NOS strategies as part of their normal science teaching. However, no information was gained from the VNOS interviews concerning how frequently these strategies were used, or to what extent NOS was deliberately being taught. The direct observation of lessons, and the TOSRA data were needed to provide this level of detail.

### **5.2.3.2 Teachers' perceptions of the effectiveness of the Nature of Science strand in terms of engaging Year 9 students, as revealed in VNOS interviews.**

All the teachers interviewed felt that teaching with a NOS perspective did increase student engagement (Research Question 1a). In the first few interviews, I limited

most of the questions to simply following up their written responses to items in the VNOS-D survey. After gaining confidence in my interview techniques and finding that teachers were giving open, honest and valuable responses, I extended the range of questions, including specifically asking if they thought using a NOS approach did engage students. Analysing the interview recordings and transcripts revealed three common themes. The first two linked NOS to the emotional and cognitive engagement of students in the classroom, while the third theme revealed some of the concerns teachers had about using a NOS approach.

Teachers who recognised that using NOS could improve the emotional engagement of students, used words like, ‘fun’ (B3, P2), ‘excitement’ (B2, C5), ‘inspire’ (B7), and ‘spark’ (B5, C5). However, P2 recognised that although using a NOS approach did improve the emotional engagement of the students this required a change from the traditional model of the teacher simply delivering the content:

*Overall my impression was that Nature of Science is better ... a much better way of engaging students. ... the questions are more open, they have choices to make, and so it is more fun and engaging ... more student oriented than teacher oriented.*

Another aspect of this emotional engagement strongly implied by several teachers (B1, B3, B7, C1), was the importance of making science relevant to the students, or showing how science and society are linked. Three teachers (B5, B6, C4), specifically stated that using a NOS approach made science more relevant to students. For example, B5 said:

*I think the nature of science is probably more of a fire starter I think, and makes it a little bit more. sort of, relevant... I little bit more real life for them.*

The second area that teachers mentioned as an effect of teaching with a NOS approach was increasing the cognitive engagement of students. Teacher B1 indicated that using a structured, explicit method of teaching about theories was very effective:

*It engaged them and actually [helped their] understanding what it means to be a theory.*

Thus implying that using NOS to improve their understanding of a concept was intellectually satisfying and therefore increased the students' engagement. Teacher P4 went further, specifically mentioning cognitive effects when I asked her directly if teaching with a NOS approach engaged students:

*Absolutely. So it's about challenge. It's that cognitive challenge.*

She went on to explain that questioning the students and encouraging them to question ideas was central to the way she taught. The use of questioning and inquiry as a key element of teaching and a way to increase engagement was referred to by most of the other teachers too (B1, B2, B3, B4, B6, B8, C3, C4, C5, C6, P2), with B8 giving a very strong justification for his use of questioning and a NOS approach:

*I started to realise, especially after the first few weeks, you realise it's not going to work by just telling them stuff, it's got to be something that they discover. And in terms of getting their enjoyment and engagement levels up, it has to be something questioning. And that kind of thing is something you have to use all the time. To let them reach their own conclusions and have that, sort of, light bulb moment.*

Thus B8 implied that finding answers to their own questions was both cognitively and emotionally engaging for students. As Fredericks et al. (2004) argued, engagement increases when students succeed in understanding concepts, especially when they realise that this success comes from their own efforts.

The third theme that emerged from the interviews was that there were difficulties delivering NOS in the classroom. The difficulties mentioned are summarised in Table 5.12, with by far the biggest problem being the lack of professional development around the teaching of NOS. The recent graduates from teacher training all expressed reservations about the guidance they received, through comments such as:

*B7: We did brief, briefly touch on it [NOS], ... but it wasn't in-depth and it wasn't practical.*

B8: *When I left T.Coll [Teacher training College] I still for a while ... I still went, what really is it [NOS]? I think there should have been more emphasis about it.*

Table 5.12

*Summary of information revealed during VNOS interviews as to the problems teachers faced when trying to teach with a NOS approach*

<b>Problem with delivering NOS</b>	<b>Teachers mentioning this problem</b>
Not covered well in teacher training	B7, B8, P1, C1, C4, C5
No professional development	B3, B4, B5, B6, P2, C6
Lack of time	B1, B2, B6, P2, C5
Lack of resources/strategies	B4, C1, C3, C6
Needs extra planning	B2, P2, P4
Pressure of delivering content	P3, C6
Easy to return to familiar ways of teaching	B1, P2
Conflicting goals of students	B2, B3
Little depth of NOS PCK	B6

Teacher B6 summed up many of the difficulties involved with the teaching of NOS with these comments:

*The new curriculum is a great, it's stuff I always like to include, but it can easily be [forgotten]. It's probably the first thing to go out of the lesson, unfortunately. Ah, it comes down to a time thing.... If, you know, you're teaching 20 hours a week, to be able to deliver, um, those things, especially being a newer teacher without the sort of, the wider experiences maybe, and longer experiences of reading things over time and relating them to different events, then it's a lot sort of harder to make those instant connections that other teachers might be able to do.*

Many of the points made by B6 and the other teachers, such as the pressure on teachers, the difficulty of producing or accessing suitable teaching resources, and the lack of pedagogical content knowledge for NOS, have been reported by many researchers (Bartholomew et al., 2004; Harland & Kinder, 1997; Hipkins, 2012), as

discussed in Chapter 2. Another side to the teachers' willingness to discuss the problems they had with teaching NOS concerned the reliability of the data being collected for this research project. I regarded the openness with which they discussed these matters as evidence that their answers were genuine and they were not simply telling me what they thought I wanted to hear concerning the benefits of NOS.

In summary, the results from analysing all the information concerning the teachers' views of NOS indicated that although all the teachers had a good understanding of NOS, and many knew of effective strategies for teaching NOS, there were considerable barriers to the regular inclusion of NOS in actual science lessons. This closely aligns with previous research (Abd-El-Khalick et al.,1998; Bartos & Lederman, 2014; Spiller & Hipkins, 2013), which found that even though teachers may agree with NOS principals, and be given considerable support, they still may not deliver it in their classrooms. The next step in this research project was to establish whether NOS was in fact being used in classrooms and if so, what were its effects on student engagement?

### **5.3 Test of Science Related Attitudes (TOSRA)**

The TOSRA surveys were given to all Year 9 students who returned consent forms in both 2013 and 2014. The survey data itself was first analysed as described in Section 5.3.1 and then interviews were carried out with both students and staff. These were a means for both checking the reliability of the data and to discover more about the thoughts and feelings of the participants concerning their experiences in science lessons. The results and analysis of these interviews are discussed in Sections 5.3.2 and 5.3.3.

### 5.3.1 Analysis of TOSRA survey results

#### 5.3.1.1 Overview

The mass of raw data obtained from both year's TOSRA surveys was analysed using iNZight, a free statistical programme developed by the University of Auckland to help interpret and visualise data (iNZight, n.d.). Only TOSRA survey results from those students present at both the beginning and end of the year were used, and only from those students who had signed and returned consent forms. Thus the actual number of students used in data analysis (sample size) was 264 in 2013 and 270 in 2014. An initial check was carried out to see if the TOSRA scores and distribution from the two groups of students (2013 and 2014) were comparable, with the results shown in Table 5.13. The measure used was the average of all seven category scores, and while essentially meaningless as a way of indicating an overall attitude towards science, it did serve to show how similar the groups were statistically.

Table 5.13

*Average score across all categories for Year 9 students who completed the TOSRA at both the beginning and end of the year.*

	<b>Mean</b>	<b>Std. dev</b>	<b>Sample size</b>	<b>Total year 9 students</b>
2013 Beginning	34.2	4.7	264	404
2013 End	33.9	5.5	264	396
2014 Beginning	35.4	5.1	270	374
2014 End	35.2	5.3	270	381

This gave me more confidence in the inferences made concerning the detail subsequently revealed by the different categories within the TOSRA. The overall scores and individual category scores were also similar in value to the ones originally

found by Fraser (1978a) in developing the instrument, which again added to my confidence in drawing conclusions from the data.

Next, the average values for each TOSRA category at the beginning and end of each year were compared for both groups of students, as shown in Table 5.14. This also afforded me opportunity to ascertain the reliability of the TOSRA scales for my chosen sample. The Cronbach (1951) alpha coefficient,  $\alpha$ , was chosen to establish internal consistency reliability of scales. As can be seen in Table 5.14, all the TOSRA scales demonstrated high reliability at both stages of implementation. Cronbach alpha reliability scores for the first year ranged between 0.67 for the scale Adoption of Scientific Attitudes, to 0.93 for Enjoyment of Science Lessons. For the second year, these scores ranged between 0.69 for the scale of Adoption of Scientific Attitudes to 0.88 for the scale of Career Interest in Science, thus reliable for use with the chosen sample (Cronbach, 1951). The statistics for both year groups were very similar, indicating that the method of data collection and the instrument itself were delivering reliable results. Overall the results indicated that the students started Year 9 with positive attitudes towards science, indicated by a score over 30, and these were maintained during the year.

The only statistically significant changes in the mean values were a slight increase in the scores for students' views on the Normality of Scientists and a slight decrease in their scores for Enjoyment of Science lessons. These changes occurred in both years while scores for Attitudes to Scientific Inquiry decreased slightly in both years – but only in 2013 with any statistical significance.

The international literature (Bolstad & Hipkins, 2008; Osborne et al., 2003b; Tytler et al., 2008; Varley et al., 2013), has described declining attitudes towards both school in general and science in particular in post-primary years, so the mostly stable values obtained from this data would appear to indicate continued engagement of students with science. In order to investigate this tentative conclusion, further analysis was conducted using the iNZight programme, particularly focussing on the categories where statistically significant changes had occurred, and on individual classes and teachers. This analysis is discussed in Sections 5.3.1.2 – 5.3.1.4.

Table 5.14

*Scale Means, Mean Differences and Internal Consistency (Cronbach Alpha Reliability) for the TOSRA surveys*

TOSRA Scale	Mean		Mean Difference	F value	Alpha Reliability
	Year Start	Year end			
Social Yr 1	36.08	36.29	0.21	0.20	0.82
Social Yr 2	37.32	38.27	0.95	3.97*	0.75
Normality Yr 1	36.64	38.33	1.69	11.39**	0.78
Normality Yr 2	37.97	40.46	2.49	24.78***	0.72
Inquiry Yr 1	39.32	37.92	1.40	7.24*	0.86
Inquiry Yr 2	39.63	38.71	0.92	1.23	0.81
Attitudes Yr 1	35.12	34.76	0.36	0.59	0.67
Attitudes Yr 2	36.74	37.44	0.70	2.45	0.69
Enjoyment Yr 1	35.06	32.85	2.21	9.92**	0.93
Enjoyment Yr 2	36.60	33.80	2.80	14.98**	0.92
Leisure Yr 1	26.99	26.59	0.40	0.36	0.89
Leisure Yr 2	28.17	26.97	1.20	2.95	0.87
Career Yr 1	30.12	30.65	0.53	0.63	0.91
Career Yr 2	31.47	30.64	0.83	1.40	0.88

N= Yr 1= 396, Yr 2= 374; \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$

Further insight into the data was provided by the comments written by students as part of the end of year survey. This free response option in the end of year electronic TOSRA, encouraged student input with the statement: *Feel free to write any comments in the box below about this survey or your experiences in science this year.* Table 5.15 shows the number of students who took up this opportunity and the main focus of their comments. Discussion regarding these comments is included in the analysis of the actual TOSRA data in the following sections.

Table 5.15

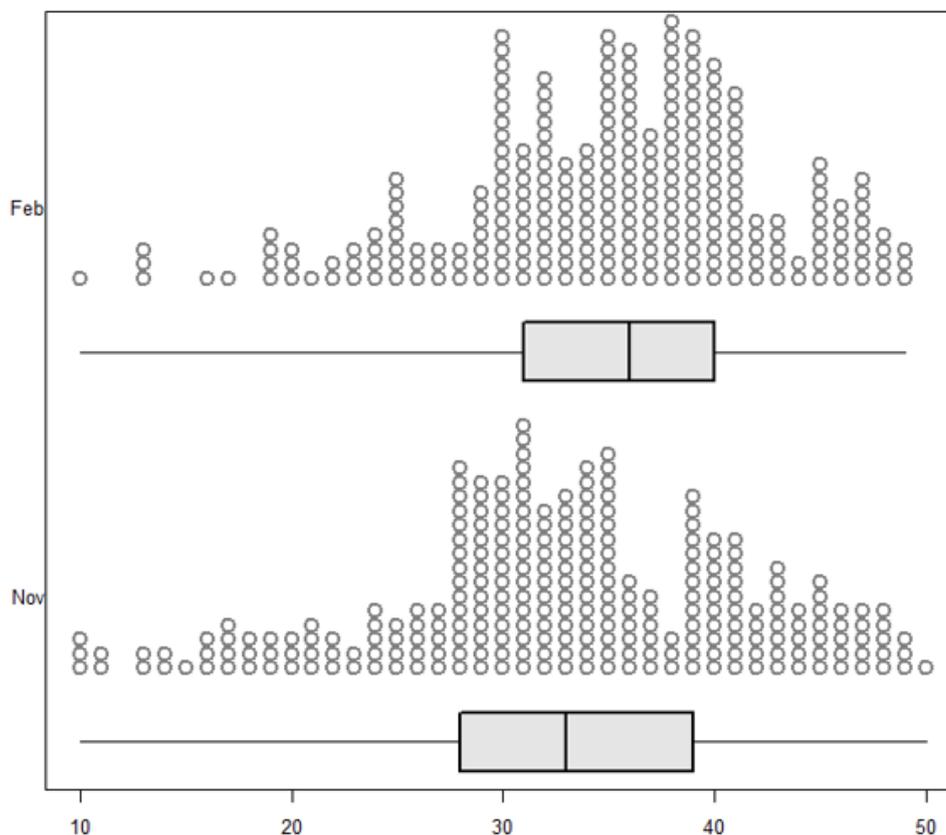
*Breakdown of student comments made on the end of year online TOSRA surveys.*

	Year 1	Year 2
Total completing online survey	260	243
Number who made comments	109	102
Students negative about survey	53	44
Students positive about survey	3	0
Students positive about science or science lessons	12	41
Students negative about science or science lessons	5	21

### **5.3.1.2 Enjoyment of science lessons**

Although the TOSRA scores for Enjoyment of Science Lessons dropped in both years, the proportion of students with a positive attitude towards this category was still high at the end of the year, as shown in Figure 5.1. A closer look at the distribution of scores revealed that seventy-five per cent of the students had a score of over 31 at the beginning of the year and over 28 at the end of the year. With a score of 30 being the mid-point of the scale, this indicated that the majority of the students enjoyed science lessons, implying that they felt at least some emotional engagement with science.

In order to target particular teachers and students, the TOSRA data on Enjoyment of Science Lessons was analysed further, enabling more precise questioning during the interviews, generating deeper insights into any links between NOS and engagement.



*Figure 5.1*

TOSRA results for Enjoyment of Science Lessons in 2013.

One example of interesting data that emerged related to the enjoyment of science and teacher B1, who taught a top science class and an e-learning class in both years. All the students in the e-learning class brought their own laptop and this was used to facilitate learning across all their subjects. The results are shown in Figure 5.2 and reveal a similar pattern in both years, with the top class changing scores a little over the year, while the e-learning class apparently experiencing a large decline in their enjoyment of science lessons. Compared to all other Year 9 classes in both years, B1's e-learning classes had the largest decline in this TOSRA category.

However, examining responses to individual questions revealed some finer detail concerning the students' attitudes and feelings towards science lessons, as shown in Figure 5.3.

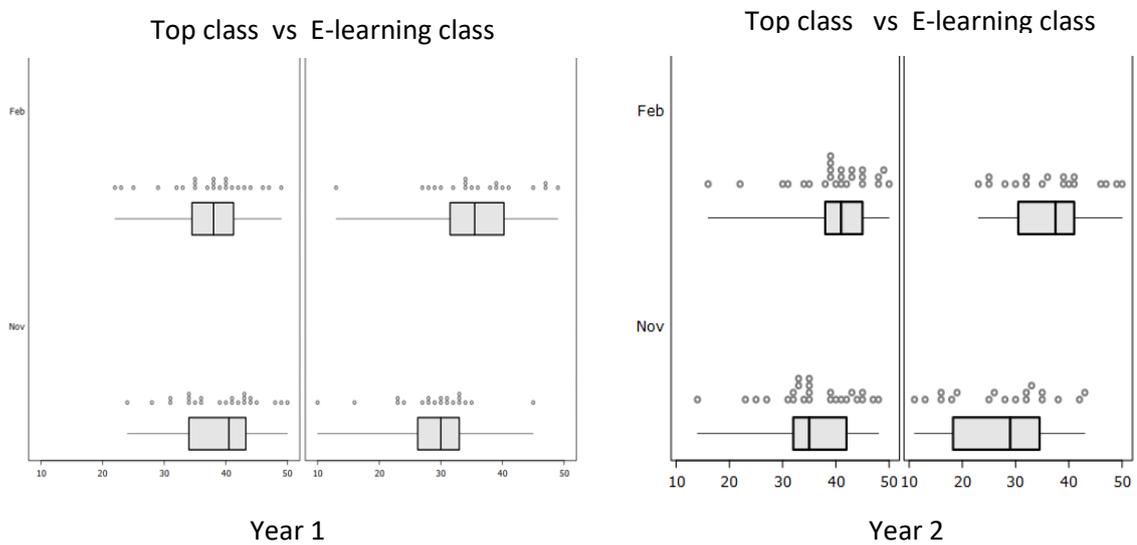
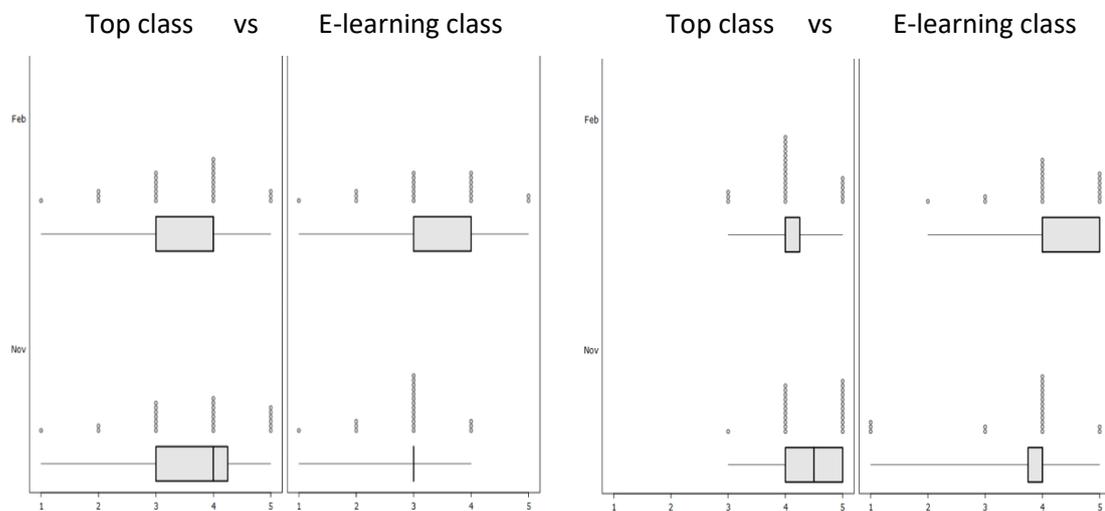


Figure 5.2

Comparison of the TOSRA category Enjoyment of Science Lessons, for the classes of teacher B1.



7. I really enjoy going to science lessons  
– a score of 5 indicates strong agreement with the statement

6. Science lessons are a waste of time  
– a score of 5 indicates strong disagreement with the statement

Figure 5.3

Comparison of two items in the Enjoyment of Science Lessons category for B1's classes in 2013.

This method of examining responses to individual items was used to analyse data in the ROSE project (Jenkins & Nelson, 2005), where scores were not combined into attitudinal categories. The information from B1's classes suggested that the top class had both emotional and cognitive engagement with science lessons. Their enjoyment of lessons remained high, while intellectually they realised the value of lessons, as shown in their positive response to item 6 at the end of the year. In contrast, the e-learning class appear to have become less emotionally engaged, with the majority of the class choosing option 3, indicating they neither agreed nor disagreed with item 7. However, they still appeared to value science lessons, shown by the majority choosing option 4 in response to item 6. This type of fine grained data proved very useful when interviewing B1 and her students, as specific questions could be asked concerning links between their TOSRA responses and what actually happened in the classroom. The same type of data analysis was undertaken with several other classes to generate useful interview questions for their teachers and students, with specific examples discussed in Section 5.3.2.

Finally, although only a small number of students made written comments concerning their enjoyment of science, the ratio of positive to negative comments was roughly 2:1 in both years, as shown in Table 5.15. Those that were positive often mentioned enjoying the experiments with comments such as:

*We did a lot of experiments this year but i would like to do a bit more because there funner to do and it's a different way of learning.*

However, as well as this emotional engagement with science and science lessons, several indicated cognitive engagement by expressing their interest in subject matter:

*Science has been really fun this year. The majority of the topics were really interesting! :)*

These sorts of comments supported the TOSRA findings of a high level of enjoyment of science lessons. However, several comments, both positive and negative, attributed much of this enjoyment or otherwise, to the influence of the teacher, as the following examples indicate:

*The teacher is nice and she makes us do fun things*

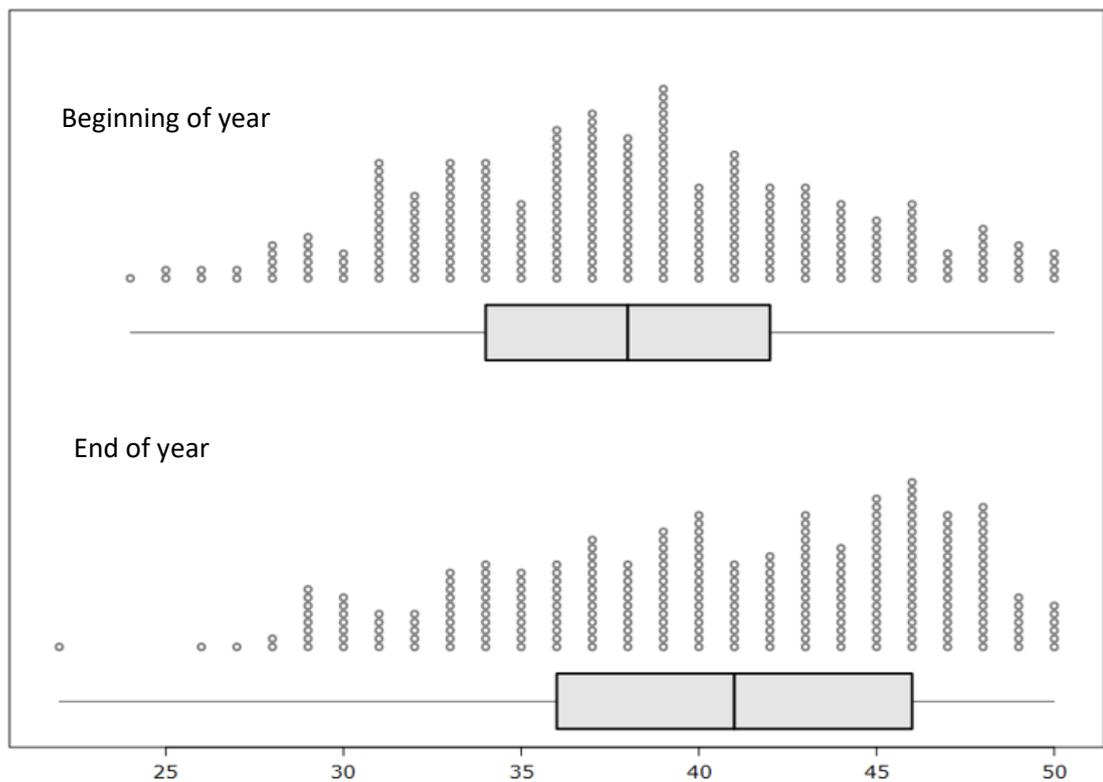
*I think that I would've enjoyed science this year if I had a different teacher. My teacher hasn't taught me what I need to know and when I ask them a question, they either ignore me or answered a completely different question which is un related to what I was wanting to know.*

Clearly, many student's attitude towards science lessons were due to a combination of the way the content was delivered, for example with a NOS approach, and the relationship between the teacher and student. The balance between these two factors was investigated further through the classroom observations and interviews.

### **5.3.1.3 Normality of scientists**

The TOSRA category, Normality of Scientists, was the only one that produced a statistically significant increase in average score based on the whole group of students in both years. The data for 2014 is shown in Figure 5.4 and indicates that the students entered Year 9 with mostly positive views and that these increased, with almost all students having an average score of over 30 points on the TOSRA scale. The ability to see scientists as normal people has been recognised as an important factor in students' emotional engagement with science (Pugh et al., 2010; Tytler et al., 2008). While Bolstad and Hipkins (2008) argued that it was vital that middle school student be able to see themselves as working in science, if they were to engage with science and consider science options in the future. Thus an increase in this TOSRA category implied that activities in the classroom were positively influencing the students' engagement with science.

As with the data on Enjoyment of Science Lessons, the Normality data was investigated further, and when broken down by class it showed that there were four teachers (B3, P1, P2 and P5) whose classes had an increase in Normality of Scientists in both years.



*Figure 5.4*

TOSRA results for Normality of Scientists in 2014.

The data for P1 is shown in Figure 5.5, and was presented to him during the interviews in order to ascertain whether he could offer any explanation for these increases based on the way he taught science and NOS. Similar questions were asked of the other teachers whose classes showed increases in TOSRA scores, as described in Section 5.3.2.

The increase in TOSRA score for Normality of Scientists suggested that at least some aspects of NOS were being covered in science classes. If students see scientists as normal people, they are likely to appreciate that scientists' own views and experiences will influence their approach to experiments and subsequent conclusions, ideas that link to the subjective/theory laden NOS theme.

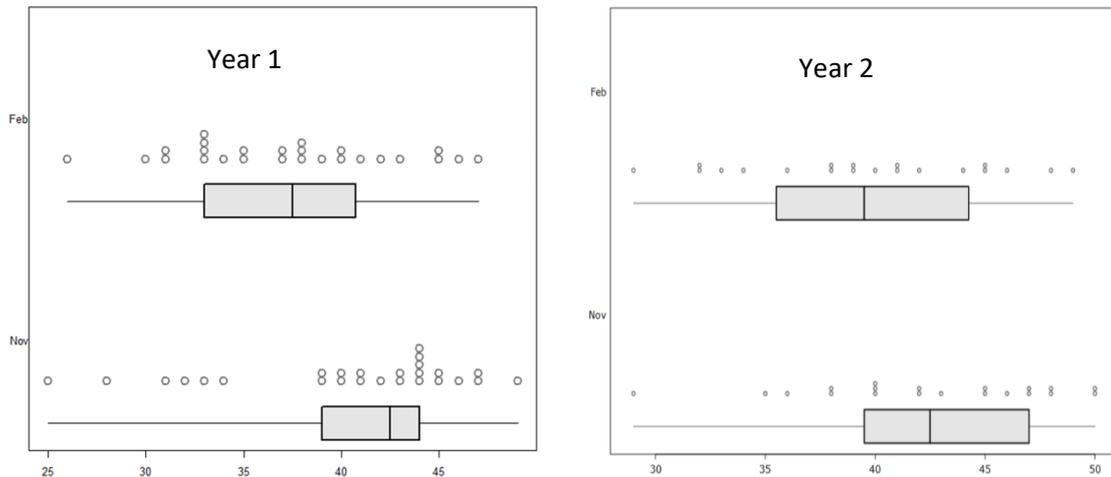


Figure 5.5

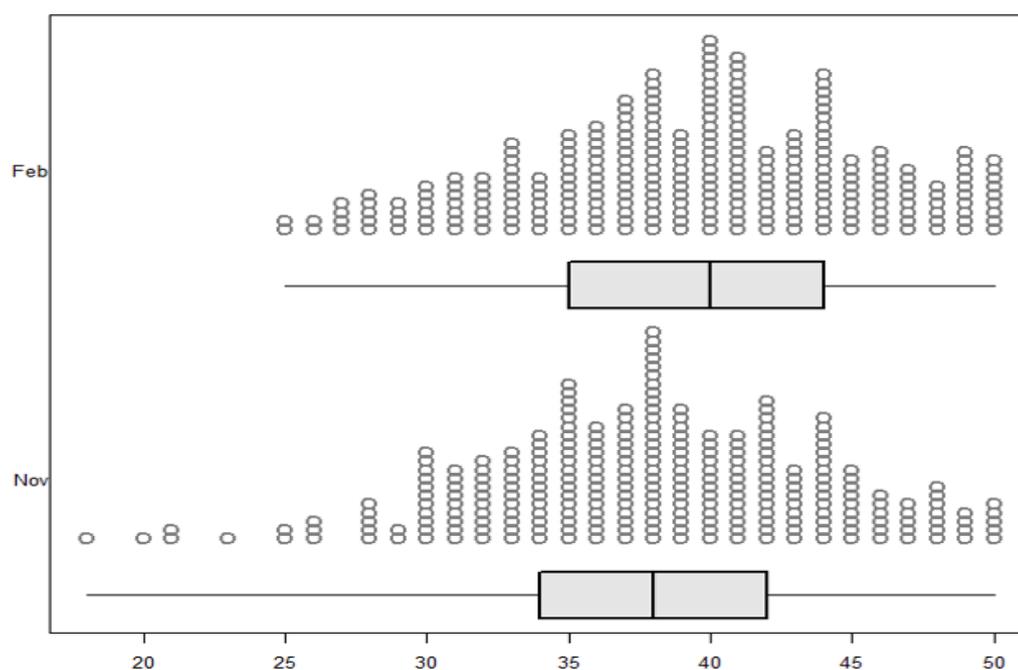
Comparison of TOSRA data for the category Normality of Scientists, for the classes of teacher P1.

Similarly, the idea that science and scientists are influenced by the society and culture in which they are situated becomes more plausible if students view scientists as normal people, doing ‘normal’ activities within their communities.

#### 5.3.1.4 Attitude toward scientific inquiry

There has been considerable debate in the research literature concerning the distinction between NOS and SI, as discussed in Section 2.3, with Osborne (2014a) suggesting that doing experiments is a good way to teach students about both inquiry and NOS. The key point about this for the TOSRA survey was that every item in the Attitude Toward Scientific Inquiry category used the word *experiment*. These ten items produced very high aggregate scores in both years of the study as shown in Table 5.14, with however a slight decrease in score in both years.

When the distribution of scores was produced using the iNZsight programme, as shown in Figure 5.6, it became clear that the overwhelming majority of students expressed positive attitudes towards scientific inquiry, both at the beginning and the end of the year. In both years 75 per cent of students still scored over 34 on the TOSRA scale for the end of year survey.



*Figure 5.6*

Results for the TOSRA category, Attitude Toward Scientific Inquiry, in 2013.

These high values supported the comments made by students written on the online form and in subsequent interviews that they enjoyed the experiments in science lesson, indicating strong behavioural and emotional engagement.

The iNZsight data also revealed differences between classes, with some increasing their score while others decreased, as shown in Table 5.16. The classes with the largest increases were the lower ability ones, but the small number of responses from these classes meant that the results should be treated with caution. However, they did prompt me to ask those teachers in follow-up interviews why they thought that some of the individuals in their classes had big increases in their attitudes towards scientific inquiry. Another interesting observation from the data was that two teachers (B1 and B2) both had one class increase their TOSRA score while the other class they taught decreased their score. The reasons for these differences were again probed during the interviews with the teachers, with the results discussed in Section 5.3.3.

Table 5.16

*Change in TOSRA score for the category, Attitude Toward Scientific Inquiry by class in 2013.*

Class	Number of student responses	Teacher	Feb mean	Nov mean	Increase (+) or decrease (-) in means
9P	6	B3	31.3	38.3	+7.0
9N	3	B3	36.3	42.7	+6.3
9Q	3	P2	30.7	34.7	+4.0
9A	24	B1	39.9	42.4	+2.5
9H	19	B4	36.1	36.9	+0.8
9K	14	B2	38.9	39.5	+0.6
9J	15	B5	37.5	36.3	-1.2
9L	20	B1	41.2	39.8	-1.4
9B	31	B7	41.0	39.3	-1.7
9D	26	P1	40.9	38.2	-2.6
9G	23	B5	37.6	34.7	-3.0
9E	26	P5	40.3	37.0	-3.3
9C	19	B8	42.5	39.2	-3.3
9F	20	B7	39.9	36.5	-3.4
9M	15	B2	37.7	32.7	-5.1

### 5.3.1.5 Attitudes towards the TOSRA survey

While the statistical information revealed much about students' attitudes towards science, it became clear from the comments made by students both in the free response section, and verbally to their teachers, that many developed a negative attitude towards the survey itself. This negative attitude may have affected their responses to the object of the survey, attitudes towards science, thus decreasing their TOSRA scores, especially at the end of the year. As Table 5.15 shows, nearly half of those students who made a written comment were negative about the survey, with many expressing similar views to this:

*i feel that these questions were very repeatitive and drived me up the wall.*

While others acknowledged the difference between the survey and the science:

*Science is fun but when you get a survey that asks you the same questions it gets annoying.*

Although these comments clearly reveal the frustration felt by some students, the willingness of students to be honest about their feelings gave me confidence that they had answered the survey questions honestly too. Even given their frustration, some students had the maturity to recognise the value of their responses to me as a researcher, as the following response shows:

*the questions are repeated so many times it starts to get a bit annoying but good luck with your research!!*

I took this kind of response as an indication that a positive relationship existed between the students and myself as the researcher, a key component of ethical research.

Feedback from some teachers also indicated a negative attitude in some students to doing the TOSRA at the end of the year, as described in Chapter 4. B1 described how her e-learning class were resistant to the survey at the end of the year:

*No, they were quite negative. I remember thinking at the time, I can't imagine this is going to be incredibly positive. [laughs]. Because they were wanting to do something else and I was having to pull them back.*

These comments may go some way towards explaining the large difference in the TOSRA results between B1's two classes in the first year, as shown in Figure 5.3, concerning the enjoyment of science lessons.

Thus while the TOSRA category, Enjoyment of Science Lessons showed the largest decline in scores over the year, part of this may have been attributable to some

negativity towards the survey itself. Once again, the interviews, particularly with students, provided a means to check whether individual scores did indeed represent their true feelings and attitudes.

### **5.3.2 Analysis of student interviews regarding TOSRA results**

#### **5.3.2.1 Overview**

The TOSRA surveys provided a mass of quantitative data which revealed some insight into students' attitudes towards science and hence their level of engagement. In order to ascertain the reliability of this data and to investigate more deeply how individuals were experiencing NOS in the classroom, interviews with both staff and students were required. These interviews were a key component of the triangulation process essential to quality research (Guba & Lincoln, 1989; Mathison, 1988; Polkinghorne, 2007). The interview transcripts were read and re-read, with the original sound recordings referred to when clarification of points were needed. Themes related to the TOSRA categories identified as having statistically significant changes were given a particular focus, although interesting findings related to other aspects of NOS emerged from the repeated analysis of the interviews.

#### **5.3.2.2 Enjoyment of science lessons**

The TOSRA data indicated that the majority of students enjoyed their science lessons, although the end of year scores were lower than the beginning in both years. Enjoyment of lessons is a strong indication of both behavioural and emotional engagement, so students were asked during the interviews to describe activities that they had enjoyed in their science lessons in order to discover if there were any connections with NOS. The students' interview responses are summarised in Table 5.17, with the majority of enjoyable experiences resulting from hands-on activities (experiments, dissections, Science Fair and other practical activities). It was evident from the students' comments that many of these activities were fun and enjoyable simply because they involved activity and not just writing:

J2: *Well, this may sound kind of weird coming from a girl, but I most enjoyed the dissections. They were awesome. It was really enjoyable, and it was fun ... being like, there as the surgeon.*

D1: *The first half [of the year] was pretty good, um, because we did a bit of practical stuff. And then the second half, it kind of got, just, really writing stuff. And it's not really fun if you just write stuff.*

The comment from student D1 concerning the balance of activities changing over the year was mentioned by a number of students and was offered as an explanation for their TOSRA scores for Enjoyment of Science Lessons dropping.

Table 5.17

*Sources of enjoyment in science lessons mentioned by the 20 students interviewed regarding their TOSRA results. \*In the second year a specific question was asked about the Science Fair.*

Activity	Number of students mentioning the activity		
	First year (11 students)	Second year (9 students)	Total
Particular topics	5	7	12
Experiments	7	4	11
Dissections	5	6	11
Science Fair*	2	8	10
Surprises ... new ideas/knowledge	5	4	9
Practical activities	6	2	8
Group work	2	3	5
Video clips	3	1	4
Quizzes/competitions	1	1	2
Challenges	0	1	1
Testing your theories/ideas	0	1	1
Computer animations	0	1	1

Student S1 for example changed her response to the item; "Science lessons are fun", from 'strongly agreeing' at the start of the year, to 'not sure' by the year's end. When questioned about this drop in enjoyment, she answered:

*S1: Yeh, because it was fun, like, but then towards the end we were doing like a lot more, like, writing down, and not doing as many practicals.*

Another reason for a decline in TOSRA scores given by students was not because they disliked the lessons, but because they had missed work or were not doing as well in assessments as they wished. For example, student W1 offered this explanation when asked about the drop in her TOSRA results:

Interviewer: *Did science lessons become less fun?*

*W1: They did at one point because I was off school for a really long time. And then I'd be really confused during lessons. When I find something hard to do and I don't understand it, I can't exactly find it fun, or interesting.*

Another student who had a large drop in her TOSRA score for Enjoyment of Science Lessons was student E3. However, during the interview she seemed to have a very positive view of science lessons, stating four times that she found science activities fun or enjoyable, including:

*Oh, I really enjoyed doing the Science project, the Science Fair thing. Dissecting eyeballs was actually pretty fun.*

When asked to explain why she thought her TOSRA score dropped in contrast to the positivity she was showing during the interview, she responded:

*E3: Well I just sort of, wasn't doing so well in my exams, so that might have sort of, brought my enjoyment in it down. Like when I failed my first test, and that probably factored in to why I wasn't enjoying it so much.*

Apart from obviously enjoying the hands-on activities, several students described gaining added enjoyment or satisfaction from the deeper understanding that these

activities brought. This cognitive engagement seemed linked to some NOS themes such as the empirical NOS and the use of observations to support theory building, as these interview extracts illustrate:

Interviewer: *And did you feel that the experiments helped you learn the theory behind it?*

E4: *I did. The one that I particularly remember that really helped me understand the theory was using iodine to stain the starch on some leaves. That one, it helped me exactly understand that it is actually there, and it is possible to see it.*

M1: *With the eye dissection, I didn't really know what an eye looked like or what she [the teacher] was talking about, with like all of it. And then I dissected the eye and then I could figure everything out.*

These comments indicated that the teachers were using experiments to enhance students' understanding of scientific concepts, not just as fun activities, a strategy recommended by Abrahams and Reiss (2012). Thus, the NOS ideas that science is based on observations which lead to explanations and theories, would seem to be implicitly used in classes.

As shown in Table 5.17, many students stated they enjoyed lessons when particular topics interested them. Although some students had difficulty explaining why they enjoyed these topics, others made reference to NOS themes and the deeper thinking that ensued, indicating cognitive as well as emotional engagement. Student D1, for example, clearly understood that science and society are linked:

D1: *I really enjoyed the Plants topic last year. That was really fun. ... I don't know why, but it was interesting.*

Interviewer: *Digging a bit deeper, why was the plant topic so interesting?*

D1: *Just kind of seeing how plants affect us, and how we affect them ... and all the different animals and creatures that affect ... that we need in our society. Like the bees, they carry the pollen.*

Another reason given for the enjoyment of experiments seemed to combine several NOS themes around observation, argumentation, and the power of the scientific method, as this discussion with R1 illustrated. The initial question was prompted by referring to R1's strong support in the TOSRA survey to the item, 'I would prefer to find out why something happens by doing an experiment than by being told':

Interviewer: *So do you believe in that, to find out things you should do experiments?*

R1: *Yeh, yeh, I prefer to find out why something happened by doing an experiment, than being told. You don't really understand, um, when people tell you. It's just more, you look at yourself, you find out. Just more believable.*

*And it makes it more enjoyable as well, doing it yourself, than people telling you for an hour, it just gets boring. And don't actually learn anything from it.*

These sorts of comments indicated that NOS ideas were being included in science lessons, but only through direct observation of lessons would it be possible to see if teachers were making the NOS themes explicit.

One aspect of the Year 9 teaching programme which had been introduced to specifically address the NOS requirements of the new curriculum, was the inclusion of a Science Fair project. In the second year of the study a question was added to the interview protocol to ask about their Science Fair projects, and whether they were engaging or enjoyable, and if so, why? Again, I did not ask anything specifically about NOS, but was interested to find that several NOS themes and factors recognised as increasing engagement emerged from their answers. For example, student V1, who had one of the largest drops in TOSRA score for Enjoyment of Science Lessons, was very positive about his science fair project:

V1: *I created ... I made a couple of antennas, to see if I could increase my wi-fi capabilities. It's just like, oh, what can affect me? What do I need? Yeh, but school's wi-fi is pretty slow, why not speed it up. It was pretty fun.*

Student V1 was very enthusiastic about his project, and was keen to show me pictures of it on his phone. He clearly appreciated the creative side of science, a NOS concept that is hard for teachers to bring out in regular lessons, but strongly encouraged in Science Fair projects. Another aspect of the Science Fair process which some students mentioned as enjoyable was related to the NOS objective in the curriculum called 'communicating in science' (Ministry of Education, 2007a). Students had to present their findings to an audience beyond their classmates and teacher, as the projects were put on display for the whole school community to see, including parents and external judges. So students were aware that their methods, results and conclusions needed to stand up to peer review, and to be successful they needed to justify their conclusions. Thus students needed to have an appreciation of the NOS themes concerning scientific method, critical testing and argumentation. A selection of interview responses illustrate these points, with students S1 and R1 obviously enjoying putting their whole investigation together and communicating it to a wider audience:

Interviewer: *Why was it [the Science Fair] enjoyable?*

S1: *Because we got to do an experiment, and then we got to make a poster, out of all our things that we found out.*

R1: *It was actually quite a lot of fun ... and then we made a video and posted it on You Tube. Loved it. The Science Fair was one of the, um, most enjoyable things from the year.*

Student J1's comments about the Science Fair process touched on some other NOS themes, such as the cooperative, empirical and tentative NOS:

Interviewer: *So was it enjoyable [the Science Fair]?*

J1: *Yeh it was, I liked working in a team, and also it was quite interesting seeing what the outcome was. It was interesting because it was different to our hypothesis, like the outcome.*

So, her enjoyment came in part, from an appreciation that her explanations for the phenomenon she was investigating were wrong, based on the observations that she made. These comments support the idea that these NOS concepts contributed to her emotional and cognitive engagement with science. They also suggest that J1's teacher had included these NOS ideas in preparing students for the Science Fair. Another comment which indicated that several NOS themes had been integrated in the science fair process came from student J2:

*It was fun [the Science Fair]. I like when we do these things. It's fun, 'cos you do the whole thing. You do the poster and you have to do the experiment, and basically kind of, makes you learn more about than just one thing.... I liked it.*

This is an example of the way Allchin (2011) suggested that NOS be delivered in the classroom. The important point being that students should be able to apply NOS concepts to situations that are relevant to themselves, rather than simply remembering key statements about NOS.

The results from the interviews clearly showed a strong connection between practical activities and enjoyment of science lessons, with added engagement due to NOS connections. However, the TOSRA data for Enjoyment of Science Lessons indicated that there were other factors influencing enjoyment of lessons, distinct from the content or method of delivery. For example, as described in Section 5.3.1.2, in both years teacher B1 had one class maintain high TOSRA scores for Enjoyment of Science Lessons, while her other class had a large decrease. One student described B1's approach in the class where TOSRA scores stayed high:

J1: *I liked the way of teaching, the experiments we do and stuff. I think it's an effective way.*

Whereas in a class where TOSRA scores declined, one student noted behavioural problems affecting enjoyment:

*E4: One lesson we did dry ice, and it was enjoyable for me but I found some of the people in the class made it less enjoyable for others. We had a certain group of boys who would not exactly focus on their work, which was not helping the class actually learn.*

Two of the students in B1's classes who had low TOSRA scores for Enjoyment of Science Lessons, agreed that their low scores were due to factors other than the science itself:

*E2: I thought that if I was put ... if we could choose our groups ... if we were put into good ones, I could enjoy it better.*

*V1: The teacher does treat us like we're quite little, which is annoying.*

Clearly, management of the class and relationship issues between teacher and students have a strong bearing on whether students enjoy lessons, and these have to be taken into account when drawing conclusions from survey data such as TOSRA, which only focuses on the science aspect of lessons.

### **5.3.2.3 Normality of scientists**

As described in Section 5.3.1.3, this category of the TOSRA survey was the only one to produce an increase in scores in both years of the study. Having realised this from the data analysis, in the second year I specifically asked the students interviewed who had large increases in their TOSRA scores, firstly whether this was a genuine reflection of their beliefs, and secondly if they could explain why their scores increased. All the students agreed that their TOSRA scores were genuine, with the reasons for these changes shown in Table 5.18.

Table 5.18

*Responses of students who had the largest increase in scores for the TOSRA category, Normality of Scientists, during interviews.*

Student	Change in TOSRA score	Reasons given for change during interview
J2	+9	Teacher made science connections with everyday life
S2	+10	Seeing the teacher as a scientist
W2	+20	Knowing more about science and scientists

As well as seeing her teacher as a scientist, Student S2 also described how they had watched videos of scientists at work, which helped her to see scientists as normal people. This view was supported by Chen and Cowie (2014), who found that the use of video clips of scientists at work helped engage students and enabled them to see themselves in those roles. Thus this strategy used by teacher, C1, had clearly been effective in engaging S2, and had also introduced one of the NOS requirements as stated in the New Zealand curriculum (Ministry of Education, 2007a, p.28): “The Nature of Science is the overarching, unifying strand. Through it, students learn what science is and how scientists work.”

#### **5.3.2.4 Attitude toward scientific inquiry**

The TOSRA data for this category showed that the majority of students had a very positive attitude toward experiments in class. The student interviews revealed more information about the source of these positive attitudes, with most students expressing the view that experiments were enjoyable. However, many of the students interviewed clearly valued experimental work beyond simply being enjoyable or fun, as shown in Table 5.19. The fundamental role of these experiments, to help understand and test scientific concepts, was evident in the students’ responses, and is at the heart of NOS (Kuhn, 1962), indicating that students were being exposed to NOS ideas in class.

Table 5.19

*Summary of student responses related to the TOSRA category, Attitudes Toward Scientific Inquiry.*

Student	Teacher	Score change	Student comments on experiments or inquiry
J2	B1	+11 33 to 44	Helped learn more
L2	B2	+11 29 to 41	Understood more doing practicals, rather than being told
J1	B1	+4 43 to 47	Experiments help remember concepts
R2	B6	+4 38 to 42	Enjoy testing theories and ideas
E1	B1	+3 37 to 40	Most students became more engaged when doing experiments
R1	B6	+2 46 to 48	Believe what I see in experiments. They are more fun and I learn more
W2	C1	+1 37 to 38	Stimulates own thinking, which helps learning
L1	B2	-1 46 to 45	Learned most from teacher demonstrating experiments and explaining them
E3	B1	-3 41 to 38	Helped to organise and remember information, especially writing up the experiments
M2	B2	-3 33 to 30	Doing experiments and seeing things for yourself helps understanding
E4	B1	-8 48 to 40	Helped understand theory. More experiments makes lessons interesting
H1	P1	-23 41 to 18	Enjoyed science fair and experiments when they worked, but always valued facts

Student J2 had the highest increase in TOSRA score and had obviously thought carefully about the role and value of experiments. She offered this explanation for the activities that most interested her in science lessons:

J2: *So I think, the more things we did with the experiments and things, it kind of stuck. Because I was having to do it not having to watch.*

Interviewer: *So the experiments helped you understand the concepts more?*

J2: *Yeh, and it kind of made me realise more, OK, this is why you do it, not just because ... yeh.* The implication from these comments, and from the flow of the interview, was that she was gaining a real appreciation of the way that science works, or as Allchin (2011) put it, the whole NOS. Later in the interview, J2 expanded on this idea:

*So, science is evolving, because the world is evolving. And there's not just one thing you can learn and be, oh yeh, I'm sweet, I know this now. There's so many other things you have to learn from that to understand the whole concept of it.*

Student J2 had clearly developed some sophisticated views about science, including the changing, tentative NOS. Another student who seemed to understand that ideas could change in response to experimental evidence was R2, with these comments explaining why he found experiments interesting and engaging:

R2: *Ah, you had to do the tests, ah, and experiment with your, like, ah, test your theories and stuff. Ah, you get to see if you're right or not. Ah, and if it was like, a new idea, you could test it and see if you're right ... Sometimes you might be wrong, but you could try again.*

R2's tone and attitude during this conversation were that he was quite happy being right or wrong, accepting the evidence from the experiments – again quite a sophisticated view of NOS.

At the foot of Table 5.19 was student H1, who had the largest decrease in TOSRA score for Attitude Toward Scientific Inquiry. During the interview she presented arguments for and against the value of experiments, and like J2 had a good understanding of the way in which science works as a whole. At one stage she was presented with her responses to the TOSRA item:

*It is better to be told scientific facts than to find them out from experiments.*

She had disagreed with this statement at the start of the year, but agreed with it by the year's end, and we began exploring the reasons for this change by investigating her prior knowledge of science:

Interviewer: *Did you do many experiments [at primary school]?*

H1: *No, I didn't. I practically did nothing.*

As she did not know anything about science, she was expecting experiments to be a good way of finding answers. But as she gained experience doing experiments she appreciated that at times they helped her learn, while in other situations they did not:

*Yeh, I think it depends what topic you're doing.... I remember in biology, I didn't like at all, any of those practicals. But I liked all the ones we did in, like chemistry.*

She also commented that she did not like it when the experiments did not work as expected, or she could not get hers to work. Although this can be a problem with school science experiments – having to complete experiments in short time frames with limited equipment – it is also an opportunity for teachers to bring in NOS ideas. When experiments do not work as expected, or produce inconclusive results, teachers can still draw out valuable points about the way science works, and the difficulties involved in getting valid results from experiments.

Student H1 also acknowledged that she enjoyed and gained knowledge from her Science Fair project:

H1: *Yes, I liked it [the Science Fair], that was good.*

Interviewer: *So you obviously felt that you learned something from it for yourself?*

H1: *Yeh, and you also learned about lots about, like, the scientific process, and like doing the hypothesis, and stuff like that.*

These comments from H1 indicated that she had been exposed to many of the NOS themes that researchers such as Osborne et al. (2003a) suggested should be included in school science classes – for example, experiencing the various methods of science and being required to make hypotheses on a regular basis. That H1 could appreciate the problems faced when doing experiments, such as inconclusive results, indicated that she understood how science works, even though at times this caused her frustration as she just wanted to be told the facts. Overall, H1 commented that she could see why her TOSRA score had declined, but she still had very positive views about science as a whole, as this final extract from the interview demonstrated:

Interviewer: *What do you think we [teachers] want you to get out of science?*

H1: *Well I think it is to show that there is so much to learn, and there is so much, like, science in the world, that there's so much to explore. And it's like, teaching you what, like, it's like in the real world.*

Interviewer: *So you think what you are learning in science is relevant to the real world?*

H1: *Yeh, I think it's important to know and also it's inspiring to know as well, because you want to learn more.*

Finally, student comments concerning the Science Fair identified some of the strategies suggested in the literature to increase engagement (see Appendix J), such as opportunities to discuss work in groups, and to work on challenging, authentic tasks, which the students chose themselves:

Interviewer: *And did you like the fact that you chose the experiment [for the Science Fair]?*

J1: *Yeh, 'cos, um, in other years we'd get like, a list of ten topics, and then we had to choose from that. Or like one large topic, and have to choose within that.*

Student S2 too, appreciated the freedom of choice in the Science Fair:

*S2: It was quite enjoyable ... because we got to do our own kind of experiments, without having to be given the task of how to do it.*

This supports the findings that giving students autonomy increases engagement (Newman, 1992), and is also a key part of NOS, that scientists have to come up with their own questions and the methods needed to answer them.

So overall, the data provided in student interviews supported the TOSRA scores recorded on the student surveys regarding Attitude Toward Scientific Inquiry. Considerable evidence also emerged to support the idea that NOS concepts were being delivered in classes and that the experimental work used to deliver these ideas was engaging for the students.

#### **5.3.2.5 Further insights gained through TOSRA related interviews**

The interviews with students regarding their TOSRA scores produced comments that related to other NOS themes which they had encountered in their classes. For example, the importance and influence of science on society was recognised by many students in their answers to the interview question, “What was the key message from Year 9 Science?” Three typical responses were:

*N1: Like, how science is pretty much everything. Like, everything has sort of, science in it.*

*E1: Science has to do with everything in life.*

*S2: That everything that you do is around science, basically.*

Probing these ideas further with one student who had a large increase in his TOSRA score for the category, Social implications of science, showed that he had received several messages about the importance of science to society.

*Interviewer: So does that ring true, that you value what science is doing in society?*

R2: *Ah, yeh.*

Interviewer: *Why do you think it's a good thing [for the government to spend money on science]?*

R2: *Ah, because it might, you'll need it to like, ah, maybe farmers and maybe vets as well. So like lots of jobs ... like you need to know parts of science to have a good job. Most jobs have science in them.*

These comments indicate that some of the changes made to the Year 9 science course in response to the new curriculum had been delivered by the teachers. One of these changes was to the learning objective sheets given to all students at the start of each topic, which now included a list of possible careers associated with that topic. Student R1 also recognised the value of science to future employment, and seemed to understand the NOS theme linking science and society, with his response to the question, "What was the key message from Year 9 science?"

R1: *That science is important ... for getting a good job, a good career. For everyone to have a better life ... scientists they discover a lot of stuff, that's important for everyone. Keep us safe as well.*

The cooperative NOS and the need for discussion or argumentation were two other NOS themes that students mentioned enjoying. As shown in Table 5.17, five students mentioned working in a group as enjoyable, with student J1 providing an example of one of these group activities:

J1: *We did the marshmallow challenge ... you had a marshmallow and you had 20 sticks of spaghetti, like a metre of tape and some string. And you had to see, like you were in groups and you had 18 minutes to build a structure to hold your marshmallow, and the highest one wins.*

Interviewer: *So what was enjoyable about that?*

J1: *Just working together as a team.*

Again, this extract highlights strategies that have been identified as both important for teaching NOS, and that engage students. Scientists work by coming up with creative ideas and solutions to problems, then collaborate and cooperate with each other while questioning and critiquing these ideas. All these NOS elements were present in the challenge J1 obviously enjoyed, but whether the teacher explicitly mentioned them as NOS ideas was not clear.

Finally, a recurring observation noted during the interviews with students was their obvious delight and enjoyment when they discussed learning new information. I found this particularly interesting having read several papers (Danaia et al., 2013; Mead & Métraux, 1957; Osborne et al., 2003b) suggesting that when students are presented with science as a body of knowledge or facts to learn, they find it boring and become disengaged. It seemed from the students' comments that when these facts were presented with a NOS approach, requiring students to think about them and apply the information to their lives, the knowledge became empowering rather than boring. As shown in Table 5.17, twelve of the twenty students mentioned particular topics as being enjoyable, while nine students mentioned learning new ideas or gaining knowledge as contributing to their enjoyment of science lessons. The sense of wonder and delight I noted from the students regarding learning new knowledge is illustrated in these comments from three different students (although the excitement conveyed by their tone of voice and body language is obviously missing):

*M1: We were learning about the body and stuff like that, and that made me think, that our body's quite amazing.*

*E3: One thing that I really remember from science last year was that atoms, learning about atoms. And that there's even in solid objects there's still moving. I found that quite interesting ... was quite weird.*

*J2: I never knew half of the things that we were using in the first place, and then we used them to create different colours, all that sort of thing. It was really cool.*

The New Zealand curriculum states that “The Nature of Science strand is the overarching, unifying strand” (Ministry of Education, 2007a, p.28), the intention being that the science content is delivered using a NOS approach. The impression that I gained from the students was that this was happening in their classes. They enjoyed experiments and were gaining much of their NOS understanding from these, as well as using the experiments to help build and understand the science content knowledge. Student J1 described how she felt her teacher, B1, had managed to successfully combine theory and practical:

*But I liked the way of teaching, the experiments we do and stuff. I think it's an effective way. ... I think what B1's doing is good. Like we do have notes to put in our book as well as experiments to help us remember it more. Like a good balance between the two.*

Thus the TOSRA survey data and student interviews did seem to suggest that many aspects of NOS were being delivered in science classes, and that these strategies were engaging the students. The extent to which this was happening and whether NOS was being explicitly taught by teachers, was further investigated by direct observations of science lessons as described in Chapter 6.

### **5.3.3 Analysis of staff interviews regarding TOSRA results**

#### **5.3.3.1 Overview**

As previously discussed, it was essential to interview the teachers in detail about the TOSRA scores concerning both the individuals and the whole class, in order to both validate the quantitative data and discover if the teaching of NOS themes was having any impact on student engagement. However, early on in each year I was also keen to feedback on the information from the TOSRA surveys to teachers, not just to check its credibility, but for them to use the results in planning for their classes. If the TOSRA data could help teachers identify which students were either very positive or negative about science, then perhaps they could devise strategies to harness and extend the positive ones, and motivate and engage the negative students. At the same time they would be providing a check to see if the TOSRA data did reflect the

attitudes of students in their classes. This approach was in line with the description Cohen et al. (2011) gave for case studies, where information gathered is often used for immediate feedback. Another reason for sharing and checking the data quickly with teachers was to build positive relationships with them, part of the sound ethical procedures outlined by Tracey (2010), and one of the eight criteria identified as being needed for excellent qualitative research.

The start of year average TOSRA score was given to each teacher, for the students in their class, and they were asked to provide a quick comment as to whether their general impressions of the students matched the TOSRA scores. They were also asked to comment on the students having the highest and lowest TOSRA scores, and whether they did show positive or negative attitudes in class. The results from the eight teachers who responded in writing, in the second year of the study, are shown in Table 5.20. The other teachers gave me a quick verbal response, which were similar to the written responses, and in general supported the TOSRA data.

The comments from the teachers also supported the initial impression that the TOSRA surveys did capture the students' attitudes towards science. Teacher C1 for example, said this about the high TOSRA score for her class as a whole:

*Not surprised by these results, they are a pretty keen class.*

While teacher P5 commented on the high score for his class:

*Results for 9G are accurate. The class is bouncing off the walls with enthusiasm.*

Similarly for individuals with high scores, the teachers had observed their positive behaviour and attitude in class with comments such as:

Table 5.20

*Feedback from teachers regarding the start of year TOSRA survey in 2014.*

Class	Teacher	Whole class data consistent with teacher's general impressions of the class	TOSRA score for most positive individual matches teacher's observations	TOSRA score for least positive individual matches teacher's observations
9A	B1	yes	yes	yes
9C	B5	yes	yes	no
9D	C2	yes	yes	no
9F	B1	yes	yes	no comment made
9G	P5	yes	yes	yes
9K	B6	yes	yes	yes
9L	B6	yes	no	yes
9M	C1	yes	no comment made	yes

B1: *has asked for extension material already*

B6: *seem to enjoy and ask questions*

Regarding the students with the lowest TOSRA scores, some were an obvious match, like this student in 9G:

P5: *The student rating least positive I agree with. She complains/moans a lot already and makes the 'this is dumb' type comments.*

However, in two instances the lowest scores appeared to be due to the individual's learning difficulties:

C1: [student] *has aspersers (sic) so I am not surprised he has the lowest score*

*B5: surprised, as he is very, very keen scientist. He started talking about Science Fair in week 2! He has dyslexia, Asperger's, dyspraxia, dysgraphia and is twice exceptional. I think the survey was difficult for him to process.*

One child with a low overall TOSRA score matched the pastoral information given to the teacher, and her impression of the child in class:

*B1: subdued, parent died last year*

One teacher noted that a student with a low TOSRA score did not match her impression of them in class, indicated she appreciated the information and would act on it:

*C2: not expected, keen to get this up.*

So as well as confirming the general reliability of the TOSRA instrument, the comments indicated that the data was useful to the teachers, providing some information that they could use to extend or support their students. The comments also began to reveal some of the individual reasons for positive or negative attitudes, some of which were not related to science lessons or NOS, such as medical issues or family circumstances.

Following the analysis of the TOSRA survey data, the combined TOSRA totals for both classes and individuals were presented to teachers before the interviews, as a way of enabling them to think about the data, and to provide a focus for questions during the interview. Questions were asked about each class concerning any significant changes in any TOSRA category scores. These discussions revealed some of the strategies teachers were using to deliver NOS ideas, and are discussed in Sections 5.3.3.2 – 5.3.3.5.

The interview data itself was then analysed as part of the triangulation process, checking if the survey responses of the students matched the teachers' perceptions of their behaviour in class. Overall, teachers agreed with the TOSRA scores for students in their classes. When asked about specific individuals in the first year of the study,

teachers noted that of the 42 students discussed, 36 of them had changes in TOSRA scores that they would have expected. In the second year teachers agreed with 30 out of 32 TOSRA scores for individual students. Some examples from the interviews serve to illustrate these results and in several cases, support the explanations for changes given by the students themselves during their TOSRA interviews.

One student who had an increase of six points in the TOSRA category Enjoyment of Science Lessons, from a score of 39 at the start of the year to 45 by the end of the year, was J2. When asked if this was expected, her teacher, B1 responded:

*She's just a lovely, outgoing kid. She really enjoyed the Science Fair. She did it by herself and really managed to go down something that interested her. She did things to do with skis. She always seemed to be positive.*

This observation matches the comments given by J2 in her interview, when she too mentioned the Science Fair as being a very enjoyable part of the year. Involvement in the Science Fair was mentioned by several other teachers as being an obvious source of enjoyment for students. For example, teacher B7 said this about a girl in 9C who increased her score in the TOSRA category, Enjoyment of Science:

*She decided half way through the year, that Science was her thing. She loved the Science Fair, something she really picked up on.*

One boy who revealed during his interview that he enjoyed the Science Fair, but had a large drop in his TOSRA score for the Enjoyment of Science Lessons was V1. His teacher, B1 was not surprised by the decline in his TOSRA scores:

*Well why did V1 not like me ... I took his phone off him most often, caught gaming most often. .... He was sort of that kid who ... on his laptop and on his device, likes to go off and do his thing.*

So it seemed that during regular science lessons V1 was disengaged and off-task, which meant the relationship between teacher and student deteriorated. However,

during the Science Fair project when V1 could follow his own interests, he became engaged and found the work enjoyable.

Another reason offered by several students to explain a drop in their TOSRA scores was their poor understanding of topics, or low test scores, often put down to missing classes. Several teachers too, noticed that students with many absences had low TOSRA scores. For example, teacher B6 was not surprised that student R1's TOSRA score for Enjoyment of Science Lessons had declined by seven points over the year:

*His test results, he's done very poorly this year. Um, he's out, he lost Tuesday afternoons period five with [Student] Council. He's lost, he's probably missed 10 to 15 lessons.*

This explanation for a decline in TOSRA scores was also given by teacher C1 for student W1:

*She's actually been sick a lot as well, so she's missed big chunks of the, um, course, which means she's failed the tests as well, which probably doesn't help her attitude towards it.*

So the interview comments from both teachers and students seemed to support the TOSRA survey data, but also suggested that NOS-related activities such as the Science Fair were enjoyable and engaging.

One interesting observation that emerged from the analysis of interview transcripts, was that students who asked questions were identified by teachers as highly engaged. When asked during the interviews if the increase in TOSRA scores for individual students reflected their views of them in class, responses such as these were common:

P2: ... *he asked quite a lot of questions, and he's very engaged.*

C1: *He's very definitely, um, keen on science. He just asks questions all the time, comes and chats to me about stuff.*

The attitude of the teachers during the interview was very positive concerning these students. They obviously welcomed the students' questions and encouraged this behaviour, thereby at least implicitly supporting the NOS themes of argumentation, discussion and critical thinking.

### **5.3.3.2 Enjoyment of science lessons**

The analysis of the TOSRA survey data revealed that while there was a slight decline in scores for the category, Enjoyment of Science Lessons, the majority of students were still positive about their experiences. The interviews with students indicated that doing practical work and experiments were the most enjoyable activities, and this view was supported by comments from the teachers. One teacher who was very explicit about the reasons for his class enjoying science was P2, as shown by this extract from his interview:

*Interviewer: Your class 9Q went up particularly in the areas of: Enjoyment (largest increase of any class), plus Normality and Careers. Is there anything you did that might account for this?*

*P2: For this particular class, 'cos it's a lower band, my primary focus was not on academic achievement. But rather than, letting them finding out what science is really about and enjoying it. And seeing the good side of science, instead of focussing on those boring side, which is memorising, and getting the right answers, and what-not. So, for this particular class a lot of lessons were practical oriented. So I did as many practicals as I could.*

This teacher clearly felt that letting the students experience NOS, or what science is about, was more important and more engaging for them than teaching the content and getting them to pass the tests. He was specifically targeting the NOS aspects of the curriculum, de-emphasising the content strands, and could clearly see the effect of this on student engagement and enjoyment in the classroom.

Most teachers, however, aimed to deliver both content and NOS, so that students could do well in tests, and have access to science courses in the future. Teacher B1

recognised the importance of academic success to many students with this comment about her class, 9A:

*They were my extension class, a quiet, studious group, who were also very competitive ... a lot of them were always trying to get the top mark and be the best.*

In contrast to teacher P2, who focussed on NOS with a low ability class, B1 had to deliver content and NOS. The analysis of her classes in Section 5.3.1.2 revealed that her top classes maintained high TOSRA scores for Enjoyment of Science Lessons, while her E-learning classes had large declines in this category in both years. The following interview extracts help explain the differences between the classes, which provide some insights into the effect of NOS and class dynamics on student engagement and enjoyment.

In relation to the top academic class, 9A, in the first year of the study:

Interviewer: *Did they ask lots of questions?*

B1: *They did ask lots of questions. Lots of questions about science. I did some things probably beyond the Year 9 ... to extend them out ... which they lapped up. They loved doing those sorts of things.*

Interviewer: *Do you think they were interested in the NOS part of it [Year 9 programme]. The social, application kind of thing?*

B1: *I definitely think they were, and of course some of that came out in the Science Fair. They really enjoyed it and were quite creative in some of the things they came up with.*

It was clear from both the interviews with B1 and with her students that she did plenty of practical work along with delivery of content, encouraging questioning and discussion in her classes. The importance and popularity of the NOS theme, argumentation was mentioned again by B1 when discussing her top class in the second year:

*They're very talkative, and very vocal, and loved class discussion, sort of, side of it.*

Clearly the inclusion of NOS themes such as argumentation, the place of science in society, and the integration of NOS with inquiry through Science Fair projects, was seen by B1 as increasing the engagement and enjoyment of her students.

However, the TOSRA data showed a decrease in Enjoyment of Science Lessons for B1's E-learning classes in both years, even though she followed the same teaching programme as with her top classes. B1 offered this explanation for the decline in TOSRA scores in her E-learning class:

*9E, they were a class that started off quite positive ... but there is a few strong personalities in there that were very vocal in what they wanted, and unfortunately they could bring the atmosphere, sometimes of the class, down, because if they were in a negative mood maybe, then the whole class could have that, "no, I'm not doing this today". And they wouldn't just sit there quietly they would be very vocal.*

It seemed that the relationships between the students strongly affected whether the class as a whole enjoyed their lessons. B1 stated that these personality problems happened across other subjects, not just in science, and went onto to qualify this:

*In saying that, you know, probably 80% of the time there was lots of positives. There were things they were very engaged with. They did really enjoy the practical side of science.*

Again, these comments were supported by the students in her classes, who as shown in Section 5.3.2.2, clearly enjoyed the experiments and practical work, but recognised some personality and behaviour issues within the class. These comments by B1 and my discussions with other teachers, during the interviews, and informally over the course of the research, led me to a deeper appreciation of the complexity of factors facing teachers. A comment I made in my field notes after interviewing teacher B2 illustrates this:

*Mostly teacher impressions of student attitudes match the TOSRA data. Students who come across positive and enthusiastic in class have high TOSRA scores, while lower scores and decreases are often attributed to non-science factors, i.e., social or personal problems such as bullying and absenteeism, which seem to affect their overall attitude towards school.*

However, even given all these other factors, it was clear that students did enjoy practical work and experiments, and that this enjoyment seemed to be enhanced when NOS themes such as argumentation, the relevance of science to society, and the critical thinking skills required for scientific inquiry, were included in lessons.

### **5.3.3.3 Normality of scientists**

Some classes had large increases in TOSRA scores for the category, Normality of Scientists, as shown in Section 5.3.1.3. The teachers of these classes were asked to offer explanations for the increases during the interviews. The responses of three teachers illustrate some of strategies used, and how they relate to NOS. First, teacher P1 had increases in this category in both years of the study, and offered this explanation:

*P1: Yeh, well that's one thing that I did try, try to each year actually, is to draw a scientist. One of the first activities I do each year is to draw a scientist ... and showing different [video] clips ... and giving them different examples of jobs and asking them if they consider those to be scientists.*

*Interviewer: And is that something that carries on through the year?*

*P1: Yeh, I do a big blast of it at the time ... but yeh, through the year I do try to point out. You know, if we're talking about something, if we see something, in another situation, I would pose the question, "Oh, does this person look like a scientist?"*

This is a good example of how explicitly teaching a concept can have a direct effect on students' attitudes. The need for the explicit teaching of NOS concepts is advocated strongly by Lederman (2007) who noted that many teachers who support,

and have a good understanding of NOS, still do not teach these ideas explicitly in their classrooms. As well as explicitly teaching about the Normality of Scientists, P1 was giving strong implicit messages about the NOS themes science and society, and the key role of questioning and argumentation in science. During the interview in the second year of the study, P1 repeated his comments from year one and added some detail concerning the strategies he used in class:

*P1: I try to make a point ... at the start of the year I get them to draw a picture of who they think a scientist is, and then I try to break down a lot of those and I try to present science as a, as stuff that happens all over the place.*

*If they, if someone comes in and explains something that they saw over the weekend, yeh, and they tried something out ... 'Oh you did science!' [is how P1 would respond enthusiastically].*

He elaborated on this during the interview, describing how he would point out to students that they were doing science when they tried different ways to solve a problem. So P1 explicitly linked the processes of science, observation, hypothesis, carrying out a method and evaluating its result or effect, to everyday situations encountered by the students. This strategy of making science relevant to the lives of students was seen as crucial by Cowie, Jones, and Otrell-Cass (2011), to engage students with science in school.

Another teacher who encouraged her students to see themselves as scientists, and whose class had a large increase in TOSRA score (+4.5) for the Normality of Scientists, was C1. She offered this explanation for the TOSRA results:

*C1: We talk about scientists, and I refer to them [my students] as scientists. But not, like it hasn't been explicit in any way ... they're a nice class and you can just chat with them.... We watch a few videos about, yeh, what scientists do.*

Almost immediately after this statement she contradicted herself, making it clear that she did explicitly tell the students that they were acting as scientists:

*They were scientists, so they were the ones asking the questions.... You guys are the scientists.*

C1 added that she encouraged the class with the kind of responses above, and that she expected that they would ask questions as they were being scientists in class. Thus C1 appeared to be using a ‘whole of NOS’ approach whereby students see how actual scientists work through video clips and then apply this to their own work in class.

Finally, teacher B6 had both his classes increase their TOSRA score for Normality of scientists in the second year of the study. During the interview, possible reasons for the changes were discussed:

Interviewer: *So did you talk about scientists?... show them examples of them?*

B6: *I linked the normality of the scientists probably more towards, you know, these are scientists, you know, this is a scientist, basically.*

One specific example B6 mentioned concerned the Rosetta Mission, where he showed some video clips of scientists working to land a space craft on a comet, and emphasised how much of the scientists’ working lives had been devoted to this project. So as well as covering explicitly the social NOS, constantly linking the work of scientists to issues facing society, B6 was implicitly mentioning the subjective, theory laden NOS – that scientists who spend their whole lives investigating some particular field are naturally going to be emotionally invested in the results. Students could clearly see the emotion involved when shown video clips of cheering scientists as news of the space craft’s landing was heard. The use of video clips however, raised another issue for B6:

Interviewer: *And what about showing clips during the year? Did you show any video clips of scientists working?*

B6: *Not lots, ah, it was more, sort of stills ... just finding pictures of ... videos would probably’ve, um, been a better approach, sort of, looking for next year.*

Interviewer: *You didn't use the Science Learning Hub?*

B6: *Nah, I sort of, am still trying to find my way, find my way around all the resources available.*

So B6 recognised the effectiveness of video clips for engaging students, but acknowledged the difficulties in finding appropriate resources to use. This was a theme that emerged several times during both the TOSRA and lesson observation interviews. Teachers had a good understanding of NOS but wanted help in finding strategies and resources to deliver this knowledge in their classrooms.

#### **5.3.3.4 Attitude towards scientific inquiry**

The TOSRA survey data revealed that students had very positive attitudes towards scientific inquiry, and the students' comments during their interviews clearly indicated that they did enjoy doing experiments. They also gained satisfaction from the deeper understanding that came when experiments helped them understand the theories involved. Thus there seemed to be behavioural, emotional and cognitive engagement when experiments were carried out in class. The interviews with the teachers supported these findings, with many acknowledging that students found experiments and practical work enjoyable, as these two comments illustrate:

B1 referring to 9E: *They did really enjoy the practical side of science.*

C1 referring to 9M: *They really enjoyed the chemistry, when there was heaps to do, you know, practical and stuff like that.*

One teacher, P5, described how simply emphasising the importance of making good observations and inferences had changed the attitude of students towards experiments:

*I can see them, they're actually approaching the experiments in a lot different manner. Whereas before they would have sit there and just mucked around they are actually now starting to, you can hear their discussions. They're actually looking at*

*things and saying right, 'Is that bubbles?' So you can actually hear some good discussion going on.*

Another change that had been made in the Year 9 course to introduce more scientific inquiry and NOS was requirement for classes to produce a Science Fair project. Therefore, in the second year of TOSRA interviews a question was specifically asked about the effect of the Science Fair. The following extract from the interview with teacher C1 shows that she felt her students were engaged by the Science Fair, and that it did prompt her to be explicit about some NOS themes:

*C1: They got quite into it [the Science Fair], I kind of gave them free range with what they wanted to do.*

Interviewer: *What do you think they liked about it?*

*C1: For maybe half of them they enjoyed the idea of coming up with something and doing it, then displaying it.*

Interviewer: *Did you discuss with them ... the NOS ideas, like fair testing and having a hypothesis?*

*C1: Yeh, we did talk about fair testing and having a hypothesis, and I tried with some of them ... tried to get them to think about the validity of what they were doing. Yeh, there were some good conversations with some of them.*

However, on reflection she decided that the students needed more guidance on these NOS aspects:

*C1: Next year, when I do it, I might spend a wee bit more time, as a class, looking at fair testing and what makes a good, like scientific project.*

These comments were repeated by several other teachers:

*P5: I think they enjoyed it [Science Fair], but they need more guidance.*

B6: *Probably the majority were pretty engaged in it [Science Fair] and, um, did some really good work.*

Interviewer: *And what do you think they liked about it?*

B6: *Getting to do what they wanted, I think. Freedom of choice. Maybe, in reflection, I should have directed a bit more.*

B1: *They worked really well [on the Science Fair]. They all worked in their teams. I had some really great stuff where the kids worked together and came up with something different. So it's nice to, to explore that, let them explore what they're interested in.*

The comments from B1 recognising the value of teamwork, supports what several of the students noted in their interviews – that they liked working and discussing things in groups. This is also an important way of modelling the way that scientists work, with collaboration and cooperation an important NOS theme.

One teacher who did put considerable effort into preparing his students for the Science Fair was P2. He explained during the interview how he had spent three periods going over fair tests, control of variables, and other aspects of investigations, so felt the students had a good grounding in this before they started their own investigations. He described the effect of this approach:

*And especially during and after the science fair, I was quite surprised. Right in the end I asked them question, 'was it worth it? And did you learn anything about it? Do you think you have a, er, more insight, in terms of what science is? And they all said yes! I enjoyed it, they enjoyed it. Which was quite surprising actually, because some of them didn't want to do it, but, but, they said they enjoyed it.*

Clearly P2 was both surprised by the success of this NOS approach and delighted by the reaction of his students.

Another teacher who was surprised at the positive effects of including a Science Fair project in his course was P1. His experiences with the Science Fair encouraged him to extend a more open-ended, NOS approach to experiments into subsequent topics:

*I got the impression that they enjoyed the freedom, of me kind of saying, 'Right you've got a couple of periods, do what you think is, is relevant. Do what you want to do.' Which is something that I've actually tried to carry on, through the, the later part of the year as well. Just because I saw how well they did respond to it.*

Thus the inclusion of the Science Fair project in the teaching programme, gave teachers the opportunity to see how effective NOS could be in engaging students, and made them realise that more explicit teaching of many of the NOS themes could lead to better outcomes for the students. Giving students more choice and control over their learning has been shown to be a key factor in improving the engagement of students (Fredericks et al., 2004; Pintrich et al., 1993). Some teachers realised this too, and so adopted a more open-ended NOS approach to scientific inquiry in their regular topic teaching.

### **5.3.3.5 Further insights gained through interviews**

As well as checking on the validity of the TOSRA data and probing the reasons for statistically significant changes in TOSRA scores, the interviews with teachers were also used to discuss strategies used in individual classes. One such discussion centred on the TOSRA scores for the category, Adoption of Scientific Attitudes. Although these did not change significantly for the whole Year 9 cohort (see Table 5.14) they did produce the highest increase for particular classes, and therefore prompted me to ask questions about possible reasons for the changes. This category was related to the NOS theme of argumentation, including items such as: "I enjoy reading about things which disagree with my previous ideas." Teacher P5 offered this explanation for his classes' improvement in TOSRA scores for this category:

*P5: We have a lot of discussion ... the real world stuff I link it to, links to the context. Hopefully promotes it. That's what I try and do, to try and get some interest.*

Interviewer: *And do they ask questions?*

P5: *Yeh, it's quite a vocal group... Some days it's just question after question after question after question. ... They're very curious. One will prompt another ... I always try and link to something outside of class. To take something that's ... trying to link it to something that's actually happened in the world. Trying to get some relevance ... I'm always full of stories. They're just ad lib stories. Some of them are well prepared. Over the years I've built a story and it's just a go to. ... as I'm doing the topic, that story will come to mind.*

Making classwork relevant to the students and the use of stories are two well recognised strategies for engaging students (Newman, 1992; Willingham, 2009) and although P5 did not claim to be specifically addressing any particular NOS theme, clearly discussion and questioning in class was encouraged, which is a key requirement of the NOS theme, argumentation.

Another teacher who encouraged argumentation in his classes was P2, who offered this description of the arguments he had with one of his students:

*He's very realistic, um, when I just tell him to do things and what-not he always asks for the rationale behind the decisions and all these instructions. And he's not being disrespectful or anything, he's a very nice guy. He's full of questions, he always asks questions, and he wants to find out about things. If he doesn't agree then he'll express, express his thoughts ... but of course he can be convinced.*

This questioning with its underlying assumption that explanations can be changed is the basis for another key NOS theme, that scientific knowledge is tentative but firm, and although not explicitly stated by P2 this was strongly implied. Similarly, teacher C1 described encouraging her students to question the things they were learning about in class:

C1: *They got really into, especially when we were doing Space, about all the 'what if?' .... And all these questions that I couldn't [answer] ... And 'how do we know if*

*there's not another planet?' The Space actually, probably sort of got them asking the most questions about, what if this? How do they know this?*

By allowing her students to ask such questions, C2 was emphasising the importance of the NOS themes of argumentation, critical thinking and peer review, and clearly these ideas were engaging the students as they were keen to be involved in the class discussions.

Another use for the teacher interviews in the second year of the study was to ask specific questions related to NOS, the curriculum and this research project. The responses of the six teachers interviewed are summarised in Tables 5.21 and 5.22 and are overwhelmingly positive concerning the value of NOS and the professional development they experienced due to their participation in the research. As well as directly contributing answers to the research questions, the comments also provided

Table 5.21

*Summary of teachers' responses to the question, "How effective do you think the Nature of Science strand in the NZ science curriculum is in terms of engaging Year 9 students in science lessons?"*

Teacher	Response	Reservations
B1	Positive – enables teacher to do more	None mentioned
C1	It's worthwhile	Not confident to teach NOS
P5	Captures student interest	None mentioned
P1	Increasingly effective	Still learning how to deliver NOS
B6	Good for average or above average students	Hard for beginning teachers to include
P2	Boosts engagement	Requires effort and the teacher must practice the techniques

Table 5.22

*Summary of teachers' responses to the question, "Have your views concerning NOS and/or its place in the curriculum changed as a result of being involved in this research project?"*

Teacher	Response	Reasons
B1	Yes	Brought the importance of NOS back to my attention
C1	Yes	Have a better understanding of its importance
P5	Yes	Added an extra dimension to practical work
P1	Yes	Makes work in class more relevant to the students
B6	Yes	Made me more confident about using NOS in class
P2	Yes	I've gained a powerful tool ... it's definitely worth the time and effort

evidence supporting the sound ethical nature of the research. These include key elements from the guidelines of the New Zealand Association for Research in Education (2010) which require the research to advance knowledge in a climate of mutual respect, and also support the idea of beneficence as recommended by the NHMRC (2007).

A more detailed look at the teachers' responses revealed some interesting points concerning the strategies teachers used to implement NOS, the effects they observed, and the ease or difficulty with which these strategies were implemented. All three of the physics teachers (P1, 2, 5) described how the small changes I had suggested to help teach NOS had made a difference:

*P2: Definitely, yes. I can tell you now that at first I was reluctant, as any teacher would be I think, to try it, or even to find out what it is. But after trying it, now I see a huge potential in this, and I believe it is definitely worth the time and effort. The interview that we had last time after the sound lesson, I, I learned a lot. Before that I don't think I even, didn't know what nature of science was.*

Thus P2 saw that simply with a change in emphasis from content to NOS he could use the same lessons but make them more relevant and engaging for students:

P2: *I believe it has huge potential [NOS], um, but again it's when used, or implemented and delivered properly to the students. It can really boost students' engagement, and make it more enjoyable. I feel like I've gained a really powerful tool that I can use, and just upgrade, um the level of my teaching. Which I'm excited about.*

Similarly, P1 had realised from the lesson observation and feedback I gave him that he was covering many NOS aspects but could increase the engagement of students by making them explicit and asking some more NOS oriented questions:

P1: *From the discussion we had last year, when you actually pointed out that it doesn't take a whole lot to actually point out: Look this is, this is what we did in class, this is how it would actually work in the, er, in the real world. I've made much more of an effort through, weekly, or maybe a couple of times a week, to try and integrate statements like that into the type of class, the type of work we are doing. Yeh, I think that it is [NOS], increasingly effective. And I'm also becoming more aware of how it is that I'm able to teach it.*

Teacher P5, too had struggled to identify what he should be specifically teaching about NOS, but had read the teacher notes I put in our Year 9 scheme and was being more explicit with his use of NOS terms during experiments:

P5: *I mean, I was a bit lost with the Nature of Science, it's a funny concept. And I wasn't really sure what the heck it was about. I had a feeling, but I wasn't sure. It's really good to give them hands-on version of it.*

Another advantage of being explicit with the language of NOS was noted by B1 who commented that her students were talking about observations vs inference during practicals at the end of the year:

B1: *You can actually now see that the learning is actually occurring. Probably it makes the learning more visible, to me as the teacher.*

So although there has been debate in the literature about the need to learn a list of tenets about NOS (Allchin, 2011; Lederman & Lederman, 2014), one advantage of at least using the terminology is that teachers can more clearly see if these tenets are being used and understood. Hattie (2009), was clear on this point from his research, strongly emphasising that teachers need to make the learning outcomes of each lesson visible and explicit.

Another interesting observation from the interviews was the difference in response between the two most experienced teachers and the remaining four with less teaching experience. Both B1 and P5, with over ten years teaching behind them, described how learning more about NOS and including these concepts in their teaching had been a valuable experience:

*B1: It's put things back in the forefront. 'Cos sometimes these can, you implement the new curriculum and then of course all the stuff piles on top of it. And it's just brought it back up to the surface again to say, yeh, this was important.*

*P5: After what, 10, 11 years of teaching, it's certainly added something new to my teaching. It's made me re-think a lot of the stuff I'm doing.*

Both teachers commented on the value of the resources I wrote and which were designed to make teaching NOS explicit:

*B1: Yes, very useful. It meant that I got to try different things, and I love to try different things.*

*P5: I found them very, very useful. I got a lot out of that Year 9 stuff, and definitely it can be used in other units... it was a gold mine, that stuff.*

So even experienced teachers needed significant support in order to change the way they delivered lessons, but once they saw the benefits, they had the skills to adapt and use the material with other classes. The less experienced teachers too, valued the NOS knowledge they had gained and could see its value in the classroom. However, they had more reservations about delivering NOS due to a number of factors:

B6: *Yeh, for me, sort of still, in my mind as sort of still learning and being a beginning teacher ... you're worrying about 20 different things, and that's probably the first one, first one to get shunted out the door.*

C1: *I do think it's worthwhile [NOS]. But I also feel, like, we have so much content to get through as well, that I don't, that I end up focussing on the content. Also because it's easier to teach the content than to teach the NOS.*

In order to help teachers deliver NOS in their classrooms, these factors need to be addressed through strategies such as reducing the content required to be taught, and providing time to practice with suitable resources. But perhaps the most persuasive technique is to demonstrate that by using a NOS approach, many of the management issues facing beginning teachers can be reduced, or indeed eliminated as the engagement of students' increases.

#### **5.4 Chapter summary**

The data presented and discussed in this chapter appeared to be consistent, with information from the TOSRA quantitative data, and the VNOS and TOSRA interviews, all supporting the same initial conclusions regarding the research questions:

- The teachers involved had a good understanding of NOS.
- The teachers used a variety of strategies to deliver NOS.
- Students reported both emotional and cognitive engagement in science lessons, often associated with carrying out experiments.
- Teachers and students both perceived teaching strategies to deliver NOS as engaging, although neither group consistently used NOS terminology explicitly.

However, it was crucial to have the direct evidence from classroom observations in order to investigate these tentative conclusions. Chapter 6, therefore, provides a detailed analysis of these lesson observations, while in-depth conclusions are made in Chapter 7, drawing together data from throughout the research project.

## **CHAPTER 6     Results and discussion related to data from classroom observations and other sources**

### **6.1 Introduction**

The data presented and discussed in Chapter 5, indicated that teachers had a good understanding of NOS and were keen to incorporate NOS in their lessons. All the teachers could describe at least one strategy they had used to deliver NOS ideas, with examples of these given in Section 5.3.2.1. Therefore, observations of lessons was a crucial part of this research, in order to verify whether those NOS strategies were being delivered by teachers, and if so, whether they had an impact on student engagement. The difficulties involved when attempting to measure the level of student engagement were discussed in Section 3.2.2, with the importance of using multiple sources of information stressed. Thus it was vital to check the findings from the TOSRA data by directly observing students in their classes. The analysis of these lesson observations is given in Section 6.2, and occupies the majority of this chapter. Finally, Section 6.3 is concerned with other data sources, such as students' subject choices, which as Osborne et al. (2003b) indicated, provide yet another tool to determine the degree of student engagement.

### **6.2 Lesson observations**

Analysis of each lesson was undertaken by re-reading the field notes from each lesson along with the interview transcripts, then combining the information into three sections: NOS themes observed; signs of engagement; and further issues related to the delivery of NOS. This allowed for triangulation of the data from all three sources: the direct observations; the follow-up interview with the teacher; and interviews with students from the class. This process was supported by re-listening to the audio recordings to ensure that comments were interpreted in context, and correct interpretations made in the light of variations in the participants' mannerisms and tone of voice.

A summary of the NOS themes observed for all ten teachers is shown in Appendix G, which also gives an indication of the teaching strategy used and whether any link

was made during the lesson to highlight the NOS theme concerned. These NOS themes were taken from the list compiled from the literature as shown in Table 2.1. As part of the analysis of each lesson in the following sections, these NOS themes were also linked to the NOS objectives as specified for Year 9 students in the New Zealand curriculum (Ministry of Education, 2007b).

### **6.2.1 Analysis of lesson taught by B7 on the Milky Way Times**

Date: May 2013

Students interviewed: None

Audio recording of lesson and teacher interview.

Lesson objective: Create a newspaper containing a range of articles as listed on the task sheet, *Milky Way Times* (see Figure 6.1).

Lesson summary:

The teacher discussed the task with the class, explaining that they had to work in groups to complete all the tasks. Students were given a written copy of the task requirements, and using laptops, spent the period finding information and organising it into their newspaper. The teacher emphasised the need for cooperation in groups and then circulated around the class helping students complete the tasks.

#### **6.2.1.1 NOS themes observed**

##### a) Socially/culturally embedded NOS

The whole *Milky Way Times* task was designed to link scientific ideas to their impact on society, with the newspaper format an attempt to make this link obvious to the students. This link was however, not made explicit by B7 in her discussions with the class, as she encouraged them to complete all the tasks on the sheet, while stressing the need for cooperation. The tasks required the students to use scientific ideas related to asteroids and a Mars colony and present them in a form that would allow informed debate in society beyond the scientific community. However, although the students may have made this link between science and society themselves, there was no direction from B7 as to the important role science plays in informing society, or that citizens need to make decisions based on this information.

## Milky Way Times

You will be working in groups to design your own newspaper. You will have two computer lessons to complete this, so you will need to do some homework.

Although you are working in groups, each member of the group needs to contribute to the paper, both in class by finding and completing work at home.

The paper has to have a name, it should be set out like a newspaper and include the following things:

- 1) An article about the risks of asteroids or comets colliding with the earth.
- 2) An article about how space travel affects the human body. Describe the problems and some of the solutions used to keep people healthy in space.
- 3) An editorial suggesting why a human base or colony is needed on the moon or planet you have chosen.
- 4) Is Pluto a planet? Find out and write an article explaining why/why not.
- 5) Create a crossword using at least 10 space words and 10 space clues.
- 6) Write 'letters to the editor' arguing for and against building a base on another planet or moon.
- 7) Write some space related adverts for the paper eg Situations vacant, Space Suit for sale, etc.
- 8) Write an article or advertisement explaining an upcoming Matariki event and what it is a celebration of.

Achieved	Merit	Excellence
All tasks completed. Articles based on facts.	Evidence of relating/linking ideas or thinking. Articles based on facts with sources of information stated.	Evidence of extended thinking. Making connections between a few Concepts. Hypotheses made and reasons given for opinions.
Basic newspaper layout  All members of the group contributed at least two pieces of work	Quality production, well set out, use of colour and pictures  Group members worked well together. Evidence of information gathered during homework.	High quality production. Attractive newspaper, done with impact and creativity  Strong teamwork evident. Information used from wide range of sources and contributed by all group members.

*Figure 6.1*

Instruction sheet and marking rubric given to students for the *Milky Way Times* task.

## b) Cooperation and collaboration

The importance of cooperating while working in groups was a key focus for B7 during the lesson. When she introduced the *Milky Way Times* task to the class, she stressed the need for cooperation and spent time getting the students to identify signs of successful cooperation:

*B7: On this piece of paper here it's going to outline eight different things that you could do. But instead of doing a whole newspaper by yourself, we work really well as a team. How do we know that we're working well as a team in this class?*

Student responses: *share ideas include everybody  
not having one person take over working together quietly, and participating  
listening to others cooperate*

B7 discussed each idea as the students answered and emphasised that in order to get an Excellence grade for the whole task, the students had to show they had cooperated, pointing out this requirement in the marking rubric (see Figure 6.1). The need for cooperation was mentioned several times by B7 and she explained her system for identifying and rewarding cooperative behaviour:

*B7: I've written the names of the groups that are working well and I've nearly got everybody's name up on the board. When I can get everybody's name up on the board we're going to have a bit of a celebration.*

Thus B7 had strategies for encouraging cooperative behaviour, but never mentioned the importance of cooperation in science generally. However, the strategies, such as explicitly discussing how to cooperate, including cooperation in the marking schedule, and writing names on the board, were good examples of how teachers can provide scaffolding to support the learning of a skill such as cooperation.

### c) Argumentation

The *Milky Way Times* task included several parts that asked students to offer their own opinions, based on the research they had done. So these NOS themes were strongly implied through the nature of the task. B7 too, emphasised to the class the need for students to apply their research to the questions and justify their opinions based on evidence:

*B7: You need evidence of extended thinking. I need to see that you have really put some thought into what you are doing, some effort, and you're starting to link contexts or different things.*

*And if you are making a hypothesis or you're coming up with your own opinions, you need to give me reasons. Why do you think that? So ask those questions, why? Why does that happen?*

However, neither the task nor B7 went the next step and explicitly stated that this is how scientists work, supporting their conclusions with evidence-based research.

### d) Creativity and imagination

The only reference to creativity in this lesson came in The *Milky Way Times* assessment rubric, which identified creativity as one of the requirements needed to gain an excellence grade. During her explanation of the task and its assessment, B7 went through the marking rubric with the class, discussing how to gain an excellence grade. When she came to the second criteria relating to the layout and presentation of the newspaper she stated:

*B7: Your finished product, your newspaper needs to be nice, high quality. You need to have put some effort into the presentation. Made it attractive. Making it look awesome.*

So she emphasised every aspect of the requirements except creativity, and did not link any of these requirements to the NOS theme that scientists have to be creative, both in carrying out their research and presenting their findings.

### 6.2.1.2 Signs of engagement

The students were obviously highly engaged with the task of producing the *Milky Way Times*, as this extract from the field notes indicated:

*30 min 9.14 Students using laptops to find information and write material for the newspaper. Quiet conversations between students. High level of engagement.*

*40 min 9.24 Same highly focused activity. Occasional quiet comments between students in groups.*

This type of high engagement was categorised as *Student Learning Conversations* by Valentine (2005), in the IPI instrument designed to help teachers identify more clearly what activities resulted in student engagement. In order to find out why the students were engaged, some were asked if they were enjoying the task:

Researcher: *Do you like working this way? ... doing research?*

Various Students:

*Yes Well it's the first thing we've done like this in science. I like it. It's fun*

*Yes, it's fun Yes, it's good*

The responses seemed to indicate that the students were emotionally engaged with the task, so a further question was asked to find out whether having a variety of tasks was important to them:

Researcher: *Is it good to have choice?*

Various Students:

– *Yes, definitely* [nodding heads, very emphatic]

– *Yes, much better than being told you have to do this*

– *Yes, like being able to choose.*

The *Milky Way Times* task was designed to include many NOS aspects, and the students clearly found the task engaging. However, as the NOS aspects were not made explicit, it is not possible to make a direct link between NOS and their engagement. That the students were more engaged than usual was revealed by B7 during the interview:

Interviewer: *Do you think the students were any more engaged in this lesson than any other?*

B7: *Well, they were definitely very focused in this. Like, I didn't, well behaviour management, getting off topic, onto other screens was definitely down, decreased ... well I didn't find anybody off topic. Whereas if I gave them a web-quest, or something, where they didn't have that collaboration maybe, or they didn't have that choice, you'd definitely pick up a couple that were straying. But they were all focused. I'd definitely use that concept again. I'd definitely try and do something like this in every topic if I can now, because it worked so well.*

Thus it would appear that that NOS elements that were part of this task did improve the degree of engagement. After discussing the lesson with B7, she indicated that she could perhaps gain even more from this NOS approach by being more explicit:

Interviewer: *Would you do anything differently if you repeated this lesson/activity?*

B7: *I'd definitely be more explicit about what I was wanting, not just the group work, but explaining why we're doing group work. It's just going to that next step of why do we do these things.*

The strategies that B7 had used to increase the cooperation between students were successful in the lesson observed, but she could see that adding in NOS connections might just improve engagement a little more.

### 6.2.1.3 Issues related to the delivery of NOS in the classroom

Although there were many NOS themes present in this lesson, B7 did not think of referring to them when planning the lesson – this despite knowing she would be observed with a focus on NOS:

*B7: I, I guess didn't explicitly. I wanted to concentrate on participation and cooperation, collaboration.*

However, the NOS themes were evidently thought about by B7 before the lesson, and on reflection she could see that there was more she could do to make them clear to the students:

*B7: I hadn't written them down. So I hadn't gone through and ticked them off. But it's in the back of my head, yeh, that I'm aiming to try and incorporate at least one or two of the Nature of Science in every lesson. But I'm not very good at writing it down. And definitely I noticed I'm not very explicit at telling the students.*

During the interview we discussed how teachers might be supported to include these NOS themes more explicitly. B7 thought that merely having the NOS statements in the curriculum document, or even the school's unit plans would not be enough to make her include them in her lessons. However, she indicated that if reference to NOS ideas were linked to specific lessons or activities, teachers would be more likely to include them:

*Interviewer: The idea, from my point of view is not to create a massive lot of paperwork, but for when you pick this up in the scheme, and it suggests you do the Milky Way Times ...*

*B7: Yeh, yeh*

*Interviewer: ...there's actually a note there that says, "This is an opportunity to be creative, or this is an opportunity to be argumentative."*

*B7: Yeh, I think that's a great idea ... I think that's much better than writing it at the top of the scheme. That's much better, to have it relevant to the different activities.*

These comments from B7, supported by similar suggestions from other teachers, prompted me to write a set of experiments with NOS themes specified in the accompanying teacher notes.

### **6.2.2 Analysis of lesson taught by B1 on the making and testing of hydrogen**

Date: May 2013

Students interviewed: None

Audio recording of teacher interview.

The primary reason for observing B1 in this lesson was to satisfy the school's requirements for appraisal and attestation of all the teaching staff. In my role as Head of the Science Faculty, I had the responsibility of ensuring all the teachers in my department were competent, and to provide professional development opportunities to help them improve and extend their practice. This lesson observation was scheduled as part of the normal cycle in this attestation and appraisal process. After discussing the situation with B1, she agreed that this lesson observation could be used as part of my research on NOS as well as for the formal school appraisal process. One consequence of this was that I did not make an audio recording of the lesson, or interview any students following the lesson, but did make an audio recording of the interview with B1, when we reviewed the lesson. The interview took place ten days after the lesson, during which time the observation write-up had been given to B1 and we had discussed this as part of the appraisal process. This gave B1 time to reflect on the lesson and even change her practice as a result of this reflection, before the recorded interview.

Lesson objectives: Describe uses and properties of hydrogen.

To make and test hydrogen.

Lesson summary:

Students brainstormed what they knew about hydrogen and its properties, then watched a video clip about the Hindenburg disaster. B1 explained how to make and test hydrogen then the students carried out this practical. Students answered

questions written on the whiteboard, then had a class discussion about the experiment and hydrogen in general.

### 6.2.2.1 NOS themes observed

#### a) Socially/culturally embedded NOS

Early on in the lesson B1 showed a video clip of the Hindenburg disaster. During the interview, B1 explained that she had deliberately chosen this clip to illustrate the properties of hydrogen in way that would engage her students:

*B1: My last year's group were engaged, so that's why I decided this year, well I would just show them as part of the lesson.*

The linking of science to events and issues in society has long been suggested as a strategy which is both useful for students, and necessary for modern societies to produce informed citizens (Davis, 1935; Fensham, 1985; Gluckman, 2013a). So B1 was aware that making links between science and society was an effective technique to engage students. However, she did not go onto discuss the importance of science to society as a NOS theme, or explore the issues that this clip raised about the adoption of new technologies.

#### b) Scientific method and critical testing

The experiment that B1 asked the students to carry out was to make and test hydrogen gas. It was presented without any NOS connections as the students were told how to do the experiment, what the result would be and what this expected result indicated. This information was given verbally by B1 with the only written instructions put on the white board shown in Figure 6.2.

Results:

1. Describe what happened in the test tube.
2. Explain what happened when the boiling tube was placed in the flame.
3. Write an equation for the reaction:  
 $\text{Mg} + \text{HCl} \rightarrow \underline{\hspace{2cm}} + \underline{\hspace{2cm}}$
4. The test for Hydrogen is called the \_\_\_\_\_ test

Figure 6.2

Writing on the whiteboard in teacher B1's lesson on Hydrogen

On reflection following our initial meeting after the lesson, and after reading of the observation report, B1 acknowledged the deficiencies in the lesson concerning NOS, and recognised that she had planned the practical part of the lesson in the same way as she had done for many years:

*B1: I think it [the lesson report] gave me some things to think about, from my own point of view ... sometimes when you get into the everyday of things, and you can just bring out the old tried and true, and know you're on the right track.*

Thus she could see the need for change and to give more guidance for students concerning the methods of science, and so made changes in her teaching practice immediately:

*B1: So what I did, I took your advice on board, and gone back to being a bit more structured with how I've written it. Included my aim, always went over method anyway, um, and divided up results and conclusion. So making sure I've followed our scientific method which will help when they're designing their own activities a bit more.*

## b) Observation vs inference

The only reference to making an observation made by B1 was through the instruction written on the board as shown in Figure 6.2, in which Question 1 required students to describe what happened. Questions 2 and 3 that followed were clearly asking for inferences based on the observations, but this was not pointed out to the students. By including them in the results section no differentiation was made between observations and inferences. This was made clear to B1 in the initial feedback, and as with the methods of science, she acknowledged the need to change her practice:

*B1: It was good to get that feedback [from the de-brief] for me, and just jolt me and say, alright, because sometimes it's the easy way when you're trying to do everything else. To still do what you've done [in past lessons] and change it, and it actually wasn't that difficult to come up with something slightly different.*

Both B1 and I received a shock from this lesson observation as we saw that even basic NOS ideas were not being delivered, even though B1 had a good understanding of NOS, and supported the intention of including NOS in the curriculum. However, having recognised this, she was quick to change her practice straight away, and seemed to maintain these changes, as noted in the lesson observation and interviews carried out in the second year of the research.

### **6.2.2.2 Signs of engagement**

As there was no audio recording for this lesson, or follow-up interview with students, the only direct evidence for engagement came from my field notes written at the time:

*The lesson was well paced with students' cooperative and engaged at all times. A variety of activities were planned and used effectively.*

However, during the interview, B1 described how she had changed her practice to include some NOS themes in a subsequent lesson, and noted a lift in student engagement. In this case she had altered her standard lesson on making and testing

carbon dioxide to include some genuine investigation, asking students to predict and test whether changing the acid affected the reaction:

*B1: I got them to be a bit more creative. I did do it with the carbon dioxide one where they did different acids on calcium carbonate. And to see which one produced the most carbon dioxide the quickest.*

*Interviewer: And do you think that engaged them, that they were keen to do that?*

*B1: Yeh, they were keen to that, because they got to do a lot more.*

B1 could see signs of behavioural, emotional and cognitive engagement straight away, as the students were more enthusiastic about getting started on the task and were asking many interesting questions related to both their observations and difficulties they faced in carrying out the experiment. This would appear to be a change from the experiment observed, making and testing hydrogen, where there was certainly behavioural engagement, but little excitement noted, nor interesting questions generated by the students. These observations support research findings (Abrahams & Reiss, 2012; Ebenezer & Zoller, 1993), suggesting that students find school science experiments engaging when they have to do more than simply follow a recipe.

### **6.2.2.3 Issues related to the delivery of NOS in the classroom**

Although the lesson ran very well with a good mix of activities, and the students well engaged and seemingly enjoying their work, I was very surprised to see the NOS aspects being delivered so poorly. The teacher was very experienced, with an excellent knowledge of NOS, a strong belief in the value of incorporating NOS in lessons, and was aware that I would be focussing on NOS. To find that despite going through the VNOS survey and interview, giving her students the TOSRA survey, and being present at science meetings where NOS was discussed, B1 was delivering NOS so poorly in her classroom was quite a shock.

The one NOS theme that B1 did plan to include in the lesson was the relationship between science and society, but unfortunately even this was not delivered well, due in part to a technical problem. B1 discovered there was no sound accompanying the video clip, and after trying to fix the problem with no success, she resorted to providing the narration herself. She acknowledged that this technical problem affected both the impact and subsequent use of the video:

*B1: I think it, sort of, fell slightly flat when you're trying to show something, because of the sound problems ... if I look at my other class, probably, they were a bit more engaged, 'cos we had a discussion around it ... because, you know, it went right the first time.*

So B1 may well have made the NOS links explicit had she not been flustered by the sound problems. This incident highlighted the problems science teachers face every day in the classroom, whether using technology to show videos or using equipment to conduct experiments. When things do not work as expected, it is easy to be distracted from making the points previously planned. This is especially so when the points are not familiar, such as with NOS themes that the teacher may not have included in previous years.

Having conducted only two lesson observations at this stage it was clear that teachers needed more support in order to make NOS ideas explicit in their classrooms:

*Interviewer: So one of the things I'm thinking of doing is perhaps writing up some of these key experiments and putting in suggestions [about NOS and how to teach it]. Do you think that would be useful in the scheme?*

*B1: I think it would be a very good idea. And it comes down to time. You know, when you teach a long time, it's probably slightly easier, but it would also help the newbees [new staff].*

The positive response from all the teachers to whom I suggested this, led to the production of a set of experiments for use in the Year 9 Reactions Matter topic, which were used by teachers in the second year of the research project.

### 6.2.3 Analysis of lesson taught by B2 on the development of ideas about elements

Date: May 2013

Audio recording of lesson and teacher interview.

Students interviewed: M3 and M4, with only field notes made, no audio recording.

Lesson objective: I understand that Alchemy is an ancient form of chemistry

Lesson summary:

Key dates and events in science were given to students on a handout (Figure 6.3).

These events were explained during whole class discussions, and students constructed a timeline of the events through individual and small group work. A cartoon video was shown of the story of Rumpelstiltskin, where straw was spun into gold. The lesson finished with the teacher discussing some of the advances due to modern science and introducing the Periodic Table, indicating this would be the focus of the next lesson.

#### 6.2.3.1 NOS themes observed

##### a) Tentative NOS

The history of science has been suggested as a good way to illustrate the tentative NOS (Allchin, 1997; Osborne et al., 2003a), as students can see that ideas once accepted as valid explanations are later rejected as alternative theories develop. This was clearly shown on the timeline (Figure 6.3) where early ideas about the elements were stated as being disproved hundreds of years later. During the lesson there were discussions between the teacher and members of the class about many of the ideas on the timeline, but the only clear statement made by B2 about ideas being replaced came at the end of the lesson:

*B2: Aristotle talked about four, maybe five elements ...but, we now know that in the universe, in our world as well, there are approximately a hundred of them. And they all exist on this Bible, of chemistry, called the Periodic Table.*

At other times the ideas of Aristotle and the alchemists were discussed, but B2 made several somewhat confusing statements, such as:

Events	Description	Other information
1700 BC	King Hammurabi's reign over Babylon	Known metals were recorded and listed in conjunction with heavenly bodies
430 BC	Democritus of ancient Greece	Democritus proclaims the atom to be the simplest unit of matter. All matter was composed of atoms.
300 BC	Aristotle of ancient Greece	Aristotle declares the existence of only four elements: fire, air, water and earth. All matter is made of these four elements and matter had four properties: hot, cold, dry and wet.
300 BC – 300 AD	The Advent of the Alchemists	Influenced greatly by Aristotle's ideas. Alchemists attempted to change cheap metals into gold. The substance used for this conversion was called the <i>Philosopher's Stone</i> .
13 <sup>th</sup> Century (1200's) – 15 <sup>th</sup> Century (1400's)	Failure of the gold business	Although Pope John XXII issued an edict against gold-making, the gold business continued. Despite the alchemists' efforts, the changing of cheap metals into gold never happened within this time period.
End of 17 <sup>th</sup> Century	Death of Alchemy	The disproving of Aristotle's four elements theory and the publishing of the book, <i>The Skeptical Chemist</i> (by Robert Boyle), combined to destroy this early form of chemistry.

*Figure 6.3*

Sample of the resource used in teacher B2's lesson showing part of the timeline. The remainder continued to the present day, including the discovery of elements and the Periodic Table.

B2: *Now let us look at what has happened since. The very last part of your timeline is about the death of Alchemy, and it happened really, because of somebody called Robert Boyle. In fact there were a lot of Alchemists or scientists making observations, but actually giving good explanations and good evidence to support their ideas. And that's really what became quite different, and they started recording it, OK.*

This lack of clarity concerning the tentative NOS seemed evident when the students were interviewed after the lesson. Student M3 showed considerable interest in the ideas of Aristotle during the lesson, and was keen to answer questions posed by the teacher. However, although he had gained some new ideas from the lesson, the idea that scientific theories are tentative and subject to change was evidently not clear in his mind:

Interviewer: *What do you think the main point of the lesson was? What did you take away from it?*

M3: *Probably the elements ... earth, fire, water, air. The Alchemy people carried it on. Then they stopped. They weren't getting interested anymore.*

While in response to the same questions, student M4 responded:

M4: *The Alchemists tried to make gold back in the old days and failed.*

During the lesson, M4 had also shown considerable interest in these ideas and at one stage had a conversation with B2:

M4: *Did they actually turn lead into gold?*

B2: *No, it's impossible.*

M4: *It can't be impossible, nothing's impossible.*

When asked about this conversation during the interview, M4 indicated that she thought that although turning lead into gold was impossible for the alchemists, it might be possible today or in the future, due to technological advancements. Thus she seemed to be indicating some appreciation that ideas, or at least processes, can change over time, an inkling that she appreciated the tentative NOS.

#### b) Empirical NOS and Observation v inference

During the lesson, B2 made several references to observations and their importance in the development of theories to explain those observations. She started one discussion by explaining what is meant by an observation:

*B2: People [Babylonians] were making observations, and an observation is where you are watching something, looking at it.*

Later in the lesson, B2 linked observations more specifically to NOS:

*B2: This is a timeline of observations, and then people trying to explain. And this really is the beginning of science, this is what science is all about ... you observe what is going on and try and you explain it.*

Thus she clearly reinforced the idea that empirical observations are the basis of science and connected these with the need to explain the observations or build theories. However, the difference between observations and inferences was never clearly explained to the students.

#### c) Argumentation

The whole lesson was conducted by B2 through a process of questioning, and encouraging the students to see different points of view. This modelled very well the processes that scientists go through when defending their explanations. When discussing Aristotle's theory of elements for example, B2 challenged the students to offer arguments of their own in support or against his theory:

*B2: I want you to look at 300BC, because Aristotle, who was a very important person, declares the existence of only four elements: fire, air, water and earth. ... Imagine, he said that everything is made up of earth ... and he said that everything, you, me, table, chairs, everything, sun, stars ... were made out of those four things. Do you think he's right?*

There was a lively discussion between the students in response to this, with some rejecting Aristotle's theory, while others attempted to explain the existence of objects through this ancient lens. B2 skilfully supported students with different views, asking them to explain why they took a certain position, and making sure that students with opposing views were listened to with respect. However, although she facilitated a good argument, she did not go the next step and explain to the students that this process is an important characteristic of the way in which science works.

#### **6.2.3.2 Signs of engagement**

Studying the history of science has long been proposed as a way of both illustrating key NOS themes and engaging students (Allchin, 1997; Osborne et al., 2003a), and this seemed to be the case in this lesson. The number and quality of the questions students asked would appear to support this view, and this was recognised by B2 who at one point in the class discussion commented:

*B2: There's lots of very deep thinking going on at the moment – good*

This was in response to the type of questions the students were asking related to the timeline, as B2 could see they were cognitively engaged. The interviews with students after the lesson seemed to support this too, as this extract from the interview with M4 indicated:

*Interviewer: What did you find the most interesting part of the lesson?*

*M4: Liked the history and how they made gold.*

M4 went on to say this was the first time she had done some history of science in a science lesson, and she enjoyed this type of learning.

The whole class responded well to B2's comments and questions about Aristotle as she challenged them to critically examine these ancient views. One boy in particular, M3, took up the theory that everything is made of four elements and used it to explain some phenomena:

*M3: If like a star, if the sun's made up of fire, so it lets off gas, which is practically air, and then heat. And then if a star is like made out of rock, so if it explodes, then it creates asteroids, which is rock, which then crashes down to earth.*

This boy, appeared to be highly engaged all lesson, asking interesting questions and keen to answer questions posed by the teacher. This was a good example of *Teacher-Led Instruction*, as categorised by Valentine (2005), when looking for signs of engagement using the IPI. In the interview following the lesson, the reasons for M3's interest were discussed:

*Interviewer: Aristotle's ideas about elements seemed to get you thinking. Do you enjoy trying to work out other viewpoints?*

*M3: Find it interesting, but it's about the first time this year that I've thought about something like that ... working out how the theory worked.*

So the NOS concepts of changing ideas or the tentative NOS, along with the encouragement by the teacher to challenge existing ways of thinking through logical argument, seemed to engage M3 and many other students in the class. These observations support findings (Sawyer, 2006; Silvia, 2008) suggesting that exposing students to new ideas, and thinking deeply about them can be very satisfying, triggering both emotional and cognitive engagement.

### 6.2.3.3 Issues related to the delivery of NOS in the classroom

This lesson illustrated many of the factors discussed by educational researchers as successful ways of explaining NOS concepts to students, such as incorporating the history of science (Solomon et al., 1992) and encouraging argumentation (Dawson & Venville, 2010). B2 was clearly intending to use this historical approach to cover some NOS concepts, as this extract from the interview after the lesson shows:

Interviewer: *Did you have specific NOS objectives in mind?*

B2: *No, I didn't refer to them from the curriculum documentation, but I was very conscious about the history of scientific discoveries being incorporated, and I know that's one of the um, um, nature of science objectives.*

Interviewer: *So you did feel you had a NOS slant to the lesson even though you didn't refer to the actual documentation.*

B2: *Yes, definitely.*

So, even though B2 intended to cover some NOS in this lesson, she had not clearly identified what those NOS themes were in her planning. This probably contributed to the lack of clarity in her delivery of NOS. This lack of planning for the delivery of NOS has previously been noted by Bartos and Lederman (2014).

Another problem for the delivery of NOS in the classroom, was the need for good resources to clearly illustrate the intended NOS themes. B2 used a timeline of historical developments in science, and although this did provide a structure for class discussion and a group activity, there were obvious flaws with the wording on the timeline. For example, the first item on the timeline regarding the Babylonians stated: *Known metals were recorded and listed in conjunction with heavenly bodies.* This information caused confusion for the students, especially regarding the 'heavenly bodies', which B2 expected them to realise meant the stars and planets, as this extract from the lesson observation shows:



*resource not really intended for science teachers or a science lesson, it was what I researched and took off.*

Interviewer: *So you don't actually know what they were doing?*

B2: *No, no I couldn't go into it in that much detail, [laughter from both interviewer and B2] for God's sake, I only have 24 hours in my day. [more laughter].*

This is a good example of a teacher who had a sound understanding of NOS, wanted to include it in her lessons, but struggled to deliver a clear understanding of NOS to her students, in part because of time and resource limitations. This problem facing teachers is well recognised as Clough and Olsen (2008, p. 144) observed: “finding and using relevant historical examples is time-consuming and difficult”. However, even given these deficiencies, it was clear from the lesson observation and interviews with the students that they were highly engaged, and enjoyed thinking about the concepts presented.

#### **6.2.4 Analysis of lesson taught by P1 on dissolving**

Date: October 2013

Student interviewed: H1 (also interviewed regarding her TOSRA scores)

Audio recording of lesson and interviews.

Lesson objectives: Dissolving and particles.

Experiment Aim: To see what solvents dissolve different solutes.

Lesson summary:

Students first looked at crystals they had made in the previous lesson, writing down their observations. Instructions were then given for an experiment where a set of five solutes were dissolved in three different solvents, and a results table drawn up.

Students copied the instructions and table, then carried out the experiment. The lesson finished with a whole class discussion on the results, with these summarised in a table on the white board, as shown in Figure 6.4.

	<b>Solute</b>				
<b>Solvent</b>	Salt	Sugar	Citrus	Vanilla	Rose
Water	✓	✓	?	✓	?
Oil	x	x	✓	?	✓
Ethanol	?	x	✓	✓	?

*Figure 6.4*

The completed data table as written on the board by teacher H1 in the lesson about dissolving.

#### **6.2.4.1 NOS themes observed**

##### a) Empirical NOS

The requirement to make good observations was stressed by P1 to the whole class at the beginning of the lesson:

*P1: Make sure that your observations are nice and clear.*

He also wrote three discussion questions on the board at the start of the lesson, one of them being:

*Is dissolving always clear? Why?*

P1 asked the students to think about this question as they did the experiment, thus indirectly emphasising the importance of making good observations in order to decide if a substance dissolved. However, these points were not linked to the critical importance of making good observations in science generally. At the end of the lesson, P1 returned to the observations made when he discussed the results table with the class:

*P1: Is dissolving always clear? I think that the data that we've got up here, up above, is pretty indicative, alright. Should be saying "Yeh, it doesn't actually always, it isn't necessarily always crystal clear".*

Thus the idea that observations are a crucial form of evidence in science was again implied, along with the notion that this evidence is not always clear. But again, these points were not linked to NOS in general.

#### b) Scientific method and critical testing

The whole lesson was structured as a genuine scientific investigation, where students had to apply their existing knowledge to explain what happened in new situations. Although the method was given, the outcomes were not and P1 encouraged the students to explain their observations using their knowledge about particles:

*P1: So we're expanding on what we learned last week, about, er, what solids dissolve in different solvents. I want you guys to start thinking more and more about what it is that you are, er, what it is that the particles are doing. Seeing if you can explain exactly what is going on with the specific particles in this situation.*

This approach illustrates the way in which science works, as described by Kuhn (1962), where many experiments are performed to test and validate the current theory. However, in this case, no link to NOS was explicitly made and nor were the students asked to make predictions concerning which solute might dissolve in which solvent.

One aspect of the methods of science that was mentioned was the importance of repeating experiments, which P1 touched on at the start of the lesson:

*P1: You guys could probably even use your very clever minds, and remember back to last week when we did this test, alright... But, test it again just to see. Science is all about repetition, right? So make sure you do test it again.*

However, there was no further reference to this when the class results were pooled and discussed at the end of the lesson.

c) Observation v inference

Although students were encouraged to make good observations, the results table the students were asked to fill in only required them to enter their inferences. This table is shown in Figure 6.4 with the symbols used indicating whether the substance dissolved ( $\checkmark$ ), did not dissolve (x), or it was uncertain if dissolving occurred (?). During the experiment, P1 circulated and responded to questions from individual students about making observations and inferences:

Student 1: *How do you know if it has dissolved or not?*

P1: *For a starter, you look at them.*

And later:

Student 2: *How do you tell if it's dissolved?*

P1: *You're going to have to use your own judgement on that.*

Thus P1 was aware of the problems which students had in making the decision as to whether the solute had dissolved. Before gathering the inferences made by the various groups of students, he stated:

P1: *These results were not necessarily always clear. I hope that you guys realised that. The results that you got weren't always just clear cut, saying yup, it dissolved, or it did not.*

This implied that there was a distinction between the observations made and the subsequent inference as to whether the substance dissolved or not. However, this distinction was never explicitly stated nor the importance of this distinction related more generally to NOS.

#### d) Argumentation

During the class discussion to collect all the various groups' results, teacher P1 expected and encouraged students to share their findings, even if they were different from others. Although P1 certainly recognised that there was an argument here that needed resolving, he did not make the NOS theme explicit and moved the discussion to a later time:

P1: *So there's a discrepancy here in, er, in water. Is it dissolving, isn't it dissolving? What's going on here? If we have time, probably won't today, we'll have to cover it next week.*

Thus although he fulfilled the requirement in the national curriculum to interpret evidence through a process of logical argument, P1 did not explain to the students that this is the way in which science works.

#### 6.2.4.2 Signs of engagement

The students appeared to be fully engaged throughout lesson. The students carried out the required tasks quickly and cooperatively, and there was definite excitement and interest in the results being observed, as shown by this audio recording from one group:

Student 3: *Look at that!* [Excited voice as a solute was added to a solvent]

Student 4: *It's so cool.*

Student 3: *I just want to watch it.*

Student 4: *Wow, look at the rose stuff.*

This illustrates how engaging experiments can be when they are presented as genuine investigations and not as recipe-type exercises where the results are already known.

This was reinforced during the interview with student H1:

Interviewer: *What did you find the most enjoyable part of the lesson?*

H1: *I think it was just seeing the different ways, how they dissolve, and like how some things don't. I think the ethanol was interesting as well because no one, because I didn't really know much about it, so I didn't really expect what was going to happen.*

So H1 was interested, or engaged, because she was finding out information herself, experiencing in just a small way, that sense and joy of discovery that science can bring, which is the motivation for many scientists.

Although many of the NOS themes were not explicitly explained in the lesson, NOS ideas were clearly present in the lesson structure and the way the teacher questioned students. This NOS approach was clearly engaging for many students, as observed when the class was asked to share their results and there was disagreement over whether a particular solute dissolved or not. P1 started the discussion by indirectly referring to the NOS idea that observations do not always result in everyone making the same inferences:

P1: *These results were not necessarily always clear. I hope that you guys realised that. The results that you got weren't always just clear cut, saying yup, it dissolved, or it did not, or ahhh, it's kind'a close. So, did salt dissolve in water?*

General agreement from the class that it did.

P1: *Did sugar dissolve in water?*

Again, general agreement that it did.

P1: *Did citrus dissolve in water?*

Variety of quite animated responses which P1 let go for a few moments:

*Yes No It did No it didn't You said it did Why did you say that?*

The students were clearly keen to offer their opinions and obviously enjoyed this limited chance to argue about their results, judging by the positive tone of their voices and the large number of students making contributions. This debate, or peer review is regarded as an essential part of science (Kuhn, 1962; Ziman, 2000) and supports research that the NOS theme of argumentation engages students (Crawford, 2005; Dawson & Venville, 2010). This view was supported by student H1:

Interviewer: *Do you like to have time to discuss things in class? ... have your ideas challenged, and so on?*

H1: *Yeh. I think that's good because you get other opinions of things, and sometimes other students can explain it in a better way than the teacher can.*

Interviewer: *Are you prepared to change your opinion as a result of those discussions?*

H1: *Ah, yeh, yeh, definitely. 'Cos I kind of just believe what the teacher says, but then sometimes the students can put it in perspective, and relate to things that I would understand.*

So not only did H1 enjoy discussion and debate, a key NOS theme, but could gain a deeper understanding of the content being covered through this process. This is a counter argument to those teachers who claim they have no time to deliver NOS ideas in the classroom as they have so much content to deliver. If they can be convinced that using a NOS approach helps the students understand and retain the content, they might be more inclined to use NOS strategies.

#### **6.2.4.3 Issues related to the delivery of NOS in the classroom**

Throughout the whole process of observation and interview, P1 was very open to constructive criticism, starting with an acceptance of the comments I had made:

Interviewer: *Was the lesson observation record and analysis an accurate account of the lesson?*

P1: *I agree with everything that's in there.*

We focussed initially on the problem with the table for collecting results (Figure 6.4) and the lack of differentiation between observation and inference:

Interviewer: *In this table here were you aware that these were all inferences rather than observations?*

P1: *Yeh, I suppose ultimately that's something that I picked up from the lower literacy classes. Where it's easier to put, yeh, as you said, make the inference, and make the data recording easier. So that's leaving the observations up to themselves and not needing to write anything down for it. Just to avoid that battle of students having to, thinking that everything about science is just writing things down.*

I suggested that if the recording of observations was presented to students as a key part of NOS, they responded positively to this and actually enjoyed writing detailed observations. P1 could see how this more explicit strategy might work in his class saying:

P1: *No that's good. I really quite like that, er, quite like that suggestion.*

This need to make NOS explicit was probed further, later on during the interview:

Interviewer: *When you planned the lesson, did you consciously think of the NOS ideas you wanted to develop in this lesson?*

P1: *No, it would be very rare that I would actually, er, do that. Um, with your feedback, your feedback is making me more aware of it. And I am making more of an effort to do that now.*

Interviewer: *So why were you not doing it?*

P1: *Well I suppose I, I may of just kind of assumed that they, er, they would have 'gotten that it was just implied as being part of the, part of the experiment.*

So P1's answers supported what Lederman (2007) has reported: that many teachers believe that by simply doing practical science the students will implicitly grasp NOS concepts. It was clear during the interview that he was beginning to see how NOS could be incorporated into the lessons he was already delivering:

P1: *What you're pointing out are very, very simple tools that I can use for that, for making the NOS explicit.*

The process we had gone through together was clearly valued:

P1: *I do appreciate the, both the subject specific stuff, like what you've given me in that report there, lesson observation. And the more broad, general things that I could incorporate into any lesson. I've actually really appreciated this conversation today, 'cos I'm walking away from this with a number of different things that I can actually use.*

Thus, the process of lesson observation, feedback and discussion appeared to be an effective way of supporting teachers to make changes in their practice and appreciate the value of teaching with a NOS perspective. The problem was the amount of time it took. My role of educational researcher enabled me to incorporate professional development alongside my own data collection, a process typical of action research (Cohen et al., 2011). However, in my normal role as Head of the Science Faculty, there was seldom enough time to complete this in-depth analysis of lessons and individual feedback of the findings.

## 6.2.5 Analysis of lesson taught by B1 on elements and compounds

Date: May 2014

Students interviewed: J1 and J3

Audio recording of lesson and interviews.

This was the second lesson observation for teacher B1 after feedback and discussion concerning the first one the previous year. She chose to use one of the experiments I had written which included some NOS elements.

Lesson objectives:

I can describe differences between compounds and the elements from which they are made.

To observe differences in physical properties between elements (iron and sulfur) and a compound formed from them (iron sulfide).

Lesson summary:

Teacher B1 questioned the whole class about atoms and elements, then went onto define compounds. Through questioning, examples of compounds were discussed and the difference between the properties of elements and compounds explored. The experiment to investigate properties of iron, sulfur and iron sulfide was introduced, students were asked to make a hypothesis and then carried out the experiment in groups.

### 6.2.5.1 NOS themes observed

a) Empirical NOS and Observation vs inference.

In her introduction to the experimental part of the lesson, B1 started by asking some questions:

*B1: A chemical reaction has to occur to know that we're making a compound. How do we know a chemical reaction is occurring? What might be some things that we look for?*

Thus the need for empirical evidence, or observations, as the basis for making a decision or inference was strongly implied, but not explicitly stated. The students responded to these questions by offering many possible observations:

Various students:      *Heat might be produced*                      *A change in colour*  
                                 *A different smell*              *Light, like maybe it'll glow a certain colour*  
                                 *Sound*                      *It might change substance, like go from a gas to a liquid*

B1 acknowledged all of these responses as possible observations and shortly before the students started the experiment reminded them:

*B1: Now we've already said looking for signs of chemical change, what they are. So things like a gas being produced, a colour change, does it change state?*

Once again she did not point out that accurate observations are required in order to make valid inferences. Another problem was her acceptance of a change of state as an observation indicating a chemical change, whereas this is usually a point cited as evidence for a physical change. Here was an excellent opportunity to distinguish between observation and inference, on two levels. Firstly the suggestion by the student, *It might change substance, like go from a gas to a liquid*, was a valid observation, but stating that it changed state is not a direct description of what was observed, but an inference based on an observation. Secondly, the inference that a change of state is good evidence of a chemical change was not justified, as it is more likely to indicate merely a physical change. Thus the situation in class presented a great opportunity to discuss these NOS issues, but possibly through lack of PCK in both chemistry and NOS, B1 was not able to use that moment to make those key points. This need for teachers to have both good NOS knowledge and PCK concerning NOS has been noted as a barrier to achieving quality delivery of NOS in schools (Abd-El-Khalick & Lederman, 2000), with Bartholomew et al. (2004) acknowledging that teachers need considerable support and training to gain the necessary PCK.

b) Scientific method and critical testing

The whole lesson structure modelled the way science is carried out, with current knowledge reviewed and then applied to new situations. These situations were then described or observed, with explanations and theories offered for those observations discussed. Finally, predictions were made on the basis of those theories, which were then themselves tested. The lesson started with a review of knowledge gained in previous lessons about atoms and elements, then a question was posed:

*B1: I've got up there a question for you. How is it possible to have so many different materials from a limited number of elements? So, has anyone got some ideas?*

Several students offered reasonable explanations based on their knowledge, which B1 built on and used to write a formal definition of a compound:

*B1: A compound is the substance produced when two or more elements combine in a chemical reaction.*

This explanation for a compound was then examined by reference to compounds that the students were familiar with, such as water and carbon dioxide. Through questioning, the students drew on their observational knowledge to establish that the constituent elements for these compounds had different properties to the compounds themselves. This led onto the experiment which tested these ideas using an unfamiliar compound, iron sulfide, with students asked to make a hypothesis:

*B1: So, when we're writing our scientific method, first of all we have to come up with a hypothesis. And you're going to predict that iron sulfide might have the same or different physical properties as iron and sulfur.*

This was the only explicit mention of scientific method in the lesson. She did however, make an important point when she asked the students to write their hypothesis:

B1: *Doesn't matter what you choose because you're going to say whether you're right or wrong at the end. You can be blatantly wrong and try and explain why you were wrong with your hypothesis.*

So B1 strongly implied that the experiment was designed to test their hypothesis and that they would have to use scientific ideas to explain their findings, which is one of the key ways in which scientists themselves describe how they operate (Jarrard, 2001; Ziman, 2000). So NOS themes were evident but students were not told that this was also how scientists operate. However, the students seemed to understand what was being implied, as demonstrated by the quantity and quality of their answers in class, and their responses during interviews. For example, at one point during the class discussion about elements and compounds, a student asked this question:

Student 1: *Does that mean that if we could change our breath into a solid that we would be able to extract diamonds from our solid breath?*

He clearly understood the theory, that carbon dioxide is made of the elements carbon and oxygen, and proposed a testable hypothesis when applying this theory to a new situation. The importance of linking scientific theory and experiments was also clear to one student I questioned during the lesson:

Observer: *What do you find interesting, do you like the practical or theory?*

Student 2: *Both practical and theory. You need the theory to understand what we are doing in the practicals.*

Similarly, during the interviews after the lesson, student J3 explained that the experiments helped her understand the theory:

J3: *I quite like having the theory, and then you have your practical lesson. It kind of makes sense as you might not get it when the class talks about it but then when you go do the experiment you might click.*

She also seemed to have gained a reasonable understanding of how science works more generally, with NOS themes related to theory building, the tentativeness of ideas, and even the role of peer review, touched on in this extract:

Interviewer: *Do you think that is also the way that science works in the wider community? That people discuss and change their ideas or do you think you discover something, and that's it?*

J3: *I think maybe you've got different people discovering things and then they might do their own line of research. And then maybe join up with someone else and then they kind of change it a wee bit, tweak it, and do it again.*

So although the NOS ideas related to scientific method and critical testing were not explicitly discussed during the class, it seemed that several students at least had picked up some key aspects through the way that B1 conducted her lessons.

### c) Argumentation

Although no examples of sustained argument were observed in this lesson, there was plenty of questioning, with the students encouraged to formulate questions of their own, or offer explanations when answering questions. However, these answers were not interrogated further, students were not asked to justify them or provide evidence for their claims as in a true argument. This type of argumentation though, did appear to take place in other lessons that B1 delivered with this class, as revealed in the interviews following the lesson:

B1: *We had a discussion the next lesson. We went over what they got in the answers, and went over the stuff that was part of the conclusion.*

Student J1 indicated that this discussion involved a degree of scientific argumentation:

Interviewer: *Do you like to discuss things in class?*

J1: *Yeh, because you get input from everyone, and you see how everyone thinks.*

Interviewer: *And do you think you are able to change your mind about things based on those discussions?*

J1: *Well, if I have a very strong opinion, then maybe they'll just contribute to what I think. But if I'm not quite sure then maybe they'll help me understand.*

Interviewer: *Do you think you would change your strong opinion if the discussion was going that way? What would it need to make you change your strong opinion?*

J1: *It would need like proper evidence. It would need, like, not just words, but like evidence. Like what we saw gave us evidence. If someone came to say you know, sulfur's pink, you know, you'd need proper evidence.*

So the culture that B1 had established in the class was one of questioning and argument, based on evidence, very much in line with NOS principles, even if not explicitly stated as such. That students find discussions and debate engaging was reported by Yazzie-Mintz and McCormick (2012), and was clearly the case in this class.

#### **6.2.5.2 Signs of engagement**

Students showed behavioural engagement throughout the lesson by their willingness to participate in all the activities with many different students answering B1's questions or offering their own ideas or questions. There was a positive conversational buzz when they were asked to discuss ideas in small groups and in the brief transitions between activities. Whether students were silently copying information from the board or carrying out the experiment, they were quick to get on with the task and no negative or disengaged behaviour was observed.

The students clearly enjoyed the experimental work, as there was a sense of excitement and interest as they got going on the practical activities. At the end of the lesson, when asked to pack up, several groups wished to carry on and test the iron

sulfide that they had made, a further indication of emotional engagement with the task. During the experiment several students were asked the question:

Researcher: *What do you think of the experiments in science?*

The responses all indicated they enjoyed the experiments:

Girl 1: *They're the funnest part of science.*

Boy 1: *I like experiments. My friend and I make black powder at home.*

Girl 2: *We like to find things out for ourselves in experiments.*

During the interviews with the students after the lesson it became clear that part of the enjoyment came from the satisfaction of understanding the theory behind their observations:

Interviewer: *What did you find the most enjoyable part of the lesson?*

J1: *I enjoyed actually doing the practical work, but I found it nice to understand what was going on.*

Student J3 put this even more strongly as she described how the pleasure gained from working independently was enhanced when she could apply the content knowledge gained from the teacher:

Interviewer: *What did you find the most enjoyable part of the lesson?*

J3: *I think when we were allowed to go off and experiment for ourselves. ... We didn't have to have a teacher with us the entire time.*

Interviewer: *So do you like finding out things for yourself? Doing experiments yourself?*

*J3: Yeh, but I think I kinda have to know what we're looking for first. So without the teaching, I think the teaching is kinda good beforehand, so that way we can. It kind of gives us a picture of what we can look for, and to understand how the reaction's working.*

Although not explicitly referring to NOS concepts in these comments, the students seemed to be gaining increased satisfaction from the implicit modelling of the way in which science works. They were not just carrying out recipe-type experiments, or doing them simply to have fun in the lesson. They enjoyed knowing that the experimental work helped them to understand or support the theories they were learning, in much the same way as scientists use experiments to test theories and develop new ideas.

There were other signs during the lesson that the students were both cognitively and emotionally engaged, particularly during the class discussions. A good example of this was when the properties of elements and compounds was being discussed. One student showed real interest and engagement with the concept through the following question, which gained immediate feedback from others:

*Student 1: Does that mean that if we could change our breath into a solid that we would be able to extract diamonds from our solid breath?*

*Student 2: wooh!*

The thought of producing diamonds from human breath was obviously exciting to many in the class for a buzz of conversation went around as they discussed the possibilities with each other. This is a good example of how new and creative ideas can captivate the imagination. It is the sort of comment that could have been used to illustrate the creative leaps that are needed to generate new ideas in science (Kuhn, 1962; Popper, 1959), a NOS theme rarely made explicit in the classroom.

### 6.2.5.3 Issues related to the teaching of NOS

Based on the lesson observation and interviews concerning the lesson, it was clear that several NOS themes were being delivered, but mostly implicitly. Rarely were clear connections made between the students' work in class and the way that science works in general. This was despite the experiment having teacher notes that pointed out this was a good experiment to make explicit the distinction between observations and inferences. This point was raised with B1 during the interview where she acknowledged that she had missed the point concerning chemical versus physical change, but was intending to look at these specifically in a later lesson. However, when asked about the lack of explicit discussion concerning observation versus inference, she responded:

*B1: No, I do, I definitely, I definitely always talk about observations. But like you said, I don't normally do the inference. But I think some of that stuff is when you're going back over the results in the final discussion.*

It was clear from the interviews with the students that the results and observations were discussed in the next lesson, revealing that many of the students had different results:

*J3: It was really interesting 'cos some people ... I think the class kind of ...It was really interesting how people kind of looked at, like they looked at different stages, of their thing.*

So B1 had facilitated a discussion about the variety of observations made by members of the class, and clearly the students were interested and engaged in thinking about these differences. However, when asked about extending these discussions to make more explicit points about NOS, B1 described the difficulty of spontaneously picking up the teachable moment:

B1: *I'm not as spontaneous and on the spot thinking, that that's where it's going to come from. You're more likely to plan it, depending on what topic it is, and how it's going to work. Rather than, coming up [clicks fingers, indicating spontaneously] ... just because someone [a student in class] says something.*

The interesting point about this comment was that this lesson had been written with a specific note to teachers pointing out that this experiment provided an excellent opportunity to discuss the NOS theme of observation versus inference. Even with this reminder, teacher B1 did not talk about this theme explicitly with the students. This illustrates how much support teachers need in order to change their practice, a point noted by Spiller and Hipkins (2013). Even when resources are provided, they still need the kind of detailed feedback and discussion that this lesson observation provided. However, the result of this feedback, and the use of further experiments with NOS themes highlighted, did seem to make a difference to B1's delivery of NOS in subsequent lessons. Evidence for this change in her practice came from the interview with B1 at the end of the year concerning the TOSRA surveys:

B1: *And even when I was doing stuff to do with slime on, last week, I even came back to observations versus inference ... going back to that stuff we've been building on throughout the year. So it's nice to have that, be explicit... and then be able to come back and see where they're at with their learning ... Could they explain what the difference was now, at the end of the year, and they could. So that was great.*

B1 had evidently changed her practice and was including explicit reference to observations and inferences in her classes, and was expecting her students to use these terms as part of their regular thinking when carrying out practical work. So teachers can and will teach NOS ideas explicitly if they see it as worthwhile and have on-going support to help them make the change.

## 6.2.6 Analysis of lesson taught by B6 on separating mixtures

Date: May 2014

Students interviewed: R1 and R3

Audio recording of lesson and interviews.

Teacher B6 was committed to delivering NOS to the extent that he deliberately chose one of the experiments I had written designed to incorporate NOS.

Lesson objectives:

Understand what a mixture is and how it can be separated.

Use a range of techniques to separate mixtures.

Explain why the mixture can be separated in term of particles.

Lesson summary:

Students were asked to explain how a variety of different substances in different mixtures could be separated, ranging from a needle in a haystack, to sand in water.

This led onto an experiment where students were challenged to produce pure samples of sand, salt and iron, from an initial mixture of all three. Students were able to use their own method or use one given to them. At the end of the lesson, the samples were judged and winners declared, followed by a brief discussion on the application of separation techniques to two industrial processes.

### 6.2.6.1 NOS themes observed

#### a) Argumentation

The first part of the lesson was presented as a puzzle, an effective strategy recommended by Staver (2007), to improve thinking skills and model the way scientists work. Students were asked to work out how to separate four different mixtures, then B6 explained what he wanted the students to do:

*B6: I want you to think about the different ways that you'd be able to separate these mixtures. So just discussing with ah, thinking first, but then discussing with your neighbour. And coming up with something that you can agree on, that you can separate.*

Thus B6 was explaining the way that scientists work, being presented with a problem, thinking about it and discussing it with fellow scientists to come up with solutions. Although this explicit link to NOS was never made, B6 added in another aspect by asking the students to use their prior knowledge to explain why their separation idea would work:

*B6: For those of you who do that really easily there's a question there: Can you explain why these mixtures can be separated?*

The buzz of excited conversation as the students discussed their ideas seemed to indicate a high level of engagement with this puzzle. When the class was called back to order to share their suggestions for solving the problems, B6 always asked each student to explain or justify why their method would work, for example:

*B6: Student 1, choose one of those ones and sort of just discuss, and just tell me what you thought was a good idea to sort of, separate them.*

*Student 1: The iron needle and the haystack. Uh, use a magnet.*

*B6: Yep, use a magnet. So why does that work Student 1?*

The student went onto explain that the iron and the hay had different properties, and the teacher reinforced these ideas and praised the student:

*B6: On Friday we ended up talking about different properties, chemical and physical properties. And so that's looking at the properties of both the hay and the metal, and being able to say, 'hey, I could actually use that'. That's a great answer [referring to Student 1].*

Furthermore, B6 then proceeded to check whether others in the class came up with a similar solution:

*B6: Hands up who thought something similar? Along the lines of using a magnet to get that.*

This process was repeated with the other separation puzzles, thus modelling many of the steps in arguing a scientific claim, with every suggestion offered by a student interrogated further, and then checked by the other students in the class. However, no explicit reference was made to argumentation or NOS.

b) Scientific method and critical testing.

The bulk of the lesson was concerned with the students solving the practical challenge as posed by the information shown in Figure 6.5, displayed in class on the screen:

<p>Separation Challenge</p> <p>Aim: Using different techniques, separate the mixture of sand, salt and iron.</p> <p>Method: Use your own ideas and the method provided to produce a sample of iron, sand and salt.</p> <p>Your sample will be judged on Purity and Quantity</p>
---

*Figure 6.5*

Instructions for students in B6's lesson on separating mixtures.

B6 explained the task to the class, and even went into some detail as to how the samples would be judged. Thus the whole task was presented from a NOS perspective, modelling the way science is carried out by scientists, such as formulating methods to test ideas and having the results open to critique or judgement. At no stage did the teacher make these links explicit, although he encouraged students to keep using their own ideas:

*B6: It's important to remember what I've given you is sort of a help sheet in case you're a little bit lost. If you've got your own ideas, go with them, OK. You're probably going to have some great ideas, go with them. The boys down the back ... they want an electromagnet, which is a great idea, they want to turn it on and off.*

During the main period of experimentation and after seeing the different techniques various students were using, B6 again praised them for being creative and using their own ideas:

*B6: There's a range of um, techniques going on. Range of um, range of order of doing things as well. So that's good that you're not just reading the instructions, that's really good, you're doing your own ideas.*

So although links with the way scientists work were not made, B6 did make it clear that he expected students to be thinking for themselves and genuinely experimenting to solve the problem, strongly implying that this was good scientific practice. The importance of setting authentic or genuine tasks was seen as crucial by Newman (1992) in order to engage students, while Tytler et al. (2008) strongly recommended tasks that required problem solving, as these reflected the work of practising scientists.

c) Socially/culturally embedded NOS.

This aspect of NOS was only briefly touched on, right at the end of the lesson when B6 put up a slide showing two examples of industrial-scale separation of mixtures in New Zealand. The first was salt production by evaporation of sea water, and the second the extraction of iron bearing minerals from iron-sand using electromagnets. B6 then made the comment:

*B6: So these techniques that you were doing on a really micro-scale are actually used in the real world, to create, ah, things that you use.*

So, although B6 did not make explicit the importance of science in shaping our modern society, this was at least implicit, and the relevance of the experiment to wider society made clear. This application of science, or the use of a scientific way of thinking, was recognised by student R3 during the interview:

Interviewer: *Do think it's important to learn about the way science works?*

R3: *Yeh, you can apply it to lots of different things. It's good to learn science, even though you might not become a scientist.*

So at least one student had picked up the idea that science was useful to individuals and society, even if this was only briefly mentioned in this lesson.

#### d) Empirical NOS

The empirical NOS was not emphasised during the lesson, but was obviously a key part of the whole experiment, as the students were told there would be a prize for the best separation. This meant observations would be required to find a winner, with the criteria for deciding which group had the best separation dependant on the purity and quantity of the samples presented. B6 even questioned the class to clarify what was meant by purity, concluding:

B6: *How pure it is. So how much of the actual one individual thing has been pulled out.*

There was no discussion as to how this purity could be measured, or that decisions about the reliability and validity of observations were often a point of debate in the scientific community. However, the importance of observations was briefly mentioned by B6 as the class worked through the experiment:

B6: *On that sheet there are some observations to write down. You can be writing down your observations. That's what we've been getting better at. Observing that things have changed.*

So, evidently the importance of good observations was something that B6 had been including in his regular lessons. The significance of these observations and the importance of the empirical NOS to students, emerged during the interviews with students after the lesson. When discussing the role of experiments in general, both students indicated they valued experiments because they could believe the evidence in front of them, as student R3 explained:

Interviewer: *Do you learn from the experiments as well, or are they just fun?*

R3: *You learn from the experiments .... Because in my mind I, I learn better doing the things, instead of just watching or reading it or something. It might not be true in a video or a book, because, in a video they might have, like, edited it or something.*

Student R1 was even more vehement in his criticism of secondary sources, putting a high value on the empirical observations he made in class:

R1: *Yeh, experiments, yeh. Not just from reading a book, or just watching You Tube videos. You actually have to do it yourself, just to make sure that ... 'cos you can't trust a book, if you don't do it yourself, can you? That's what I think. So, it's, kind of fun doing experiments, and you can also believe it 'cos you've done it yourself.*

This sceptical attitude to the information they are exposed to was a good sign that ideas related to the empirical NOS had been conveyed to them by B6, through the medium of experiments.

#### **6.2.6.2 Signs of engagement**

The students were highly engaged throughout the lesson, but particularly so when presented with the separation challenge, where groups were actively applying techniques to separate the components of their mixtures. This was a good example of *Student Active Engaged Learning*, as described by Valentine (2005). As soon as B6 asked the students to discuss in their groups how they would separate the components, an excited buzz of conversation went around the room. The field notes written at the time capture some of this excitement from one group sitting near me at the back of the room:

*Boy group 1 (in back corner of lab): Responded very positively to the challenge, immediately discussing ideas. First idea was to boil water. Excited by the idea of using an electromagnet to pick up the iron and then get it off. Went on to realise that they could wrap the magnet in paper to achieve the same goal. Were disappointed*

*when B6 pointed out to the whole class that they should wrap cling film around the magnet.*

It appeared that this group was behavioural, emotionally, and cognitively engaged with the task, really enjoying the challenge and gaining immediate satisfaction from solving part of the puzzle. This type of response was noted by Pintrich and DeGroot (1990) when students tackled authentic, challenging tasks, and Allchin et al. (2014), when these tasks involved NOS.

Student R3 supported this notion that the task was both emotionally and cognitively engaging:

Interviewer: *Did you like designing the experiment yourself, trying to work out how to do it?*

R3: *Yeh, because you had to use your mind instead of being told exactly what to do. Which is more fun than just reading the instructions.*

These comments support previous studies (Ebenezer & Zoller, 1993; Woods-McConney et al., 2013), which reported high levels of engagement when students were given choice and control over how they carried out experiments.

Another sign of both emotional and cognitive engagement was the surprise registered by many students when they saw the salt appearing while boiling off the water in the final step of their experiment. This extract from the field notes conveys the experiences and feelings of one group:

*Girl group 3: [eventual joint winners] As they were watching the salt water evaporate one girl said: "We didn't actually know if there was salt in there because we couldn't see it". She went on to comment that they were very glad to see the salt appearing during the evaporation. Near the end, when they had arranged the separate samples for judging, they were very keen to get the teacher over for a look and exclaimed with joy: "Yay, we did it!"*

There was a similar sense of excitement from many students at the time as they experienced the intellectual thrill of seeing something they had doubts about actually happen in front of their eyes. Student R3 seemed to support the idea that part of the surprise came from her doubts about the theory being correct:

Interviewer: *So were you surprised to see the salt appearing when you evaporated it off?*

R3: *Well, I didn't really think it would work, but, you know, it did. I knew it was there, but, I didn't think it would have that much.*

She also expressed satisfaction that her group was able to complete the task and solve the challenge:

Interviewer: *What did you find the most enjoyable part of the lesson?*

R3: *Like, seeing what we can do with it. .... It's fun to do experiments, because, like, you're doing stuff instead of just watching it. It was interesting that we could do it, and we're only Year 9's and stuff.*

So there appeared to be an emotional reward for R3 in completing the task which seemed particularly satisfying as she viewed it as a genuine challenge, an authentic task which was worth putting in effort to solve. The desire to achieve competency was described by Newman et al. (1992) as one of the most powerful motivating forces that people experience, recommending that teachers set up tasks such as the one used in this lesson to increase student engagement. Teacher B6 acknowledged the increased effectiveness of this task which engaged even those students who were not normally so involved:

B6: *The ones who sort of, science isn't their number one, they sort of, those ones were sort of wrapped into it as well. So that challenge aspect certainly brought them in, a bit more, than potentially just doing a sort of, separate this, um. Bringing that competition side into it brought those, ah, students into it.*

These are the sorts of experiences which teachers need if they are to continue using a NOS approach, especially if that increased cognitive engagement leads to improved learning outcomes. These improved outcomes, in the form of a better understanding of the concept of dissolving, were reported by B6 during the interview:

*B6: It was also really good [the separation challenge lesson], in terms of reflecting on that lesson. 'Cos they were into it 'cos they were engaged in it they all remembered it, they all saw it happen.... When you asked that question, there were lots of hands going up, to sort of, offer responses.*

*Interviewer: So because they were engaged in that lesson particularly, it was really easy to refer back to.*

*B6: Yeh, and I think they felt good about the fact that they could explain something that they'd done, that was very vivid in their memory.*

Thus it appeared that using a NOS approach not only increased the engagement of students at the time, but made it easier for them to understand and remember the scientific concepts.

### **6.2.6.3 Issues related to the delivery of NOS in the classroom**

Even though B6 noted increased engagement of students in this lesson and reported positive learning outcomes regarding the scientific concepts, he still expressed some concern as to whether this type of lesson could deliver the content required. He suggested a way of making sure this content was included:

*B6: I guess then just as long as the conclusion, as a strong conclusion to whatever you've done. Then the same learning is going to be done. As long as you have that, sort of, conclusion, and bring it back to the relevant points.*

Thus B6 was prepared to use this NOS approach as long as the scientific concepts for the topic were clearly covered in the conclusion. Based on the lesson observed and the comments made about the students' understanding of dissolving, this seems a

very effective method, with the NOS approach actually enhancing the students' understanding.

During the interview, B6 raised another concern, related to the open-ended task given to the students. He was worried when preparing for this lesson that the students would not be able to solve the puzzle and separate the mixture, based solely on their own ideas. This is why he gave them a method that would work:

*B6: It's just that you wanted the task to be successful, so you just wanted a sort of, fall-back for them.*

This was an understandable precaution as although he wanted the task to be challenging, he did not want them to fail. This balance for the teacher is one that can only be gained by experience, learning how much, and when to give any scaffolding needed. Sawyer (2006) saw this scaffolding as essential for teachers to set students up for success, especially when students were set challenging problems. However, the rewards were great in terms of increased emotional and cognitive engagement of the students. It is also a risk for teachers having to let go of the total control they are used to in the traditional style of teaching, even to the extent of letting some students fail. However, B6 could see the value in discussing why some methods worked while others did not:

*B6: Some of them had things go wrong. And, um, for them, they probably learned, you know they learned a lot. It's not the end of the world, and um, some of them were persevering too far, when it was OK to say, hey, I've done this wrong.*

He could see that there were important lessons for life beyond the classroom from letting students choose their own path, and even remembered a question that he had asked one group during the lesson:

*B6: At what point are you going to, sort of, at what point are you going to change what you're doing? Because this obviously isn't working.*

So here was a deeper challenge within the challenge, requiring students to think critically about their own actions. This critical thinking is a key part of NOS and also an objective of many science curriculum documents around the world (ACARA, 2013; NGSS Lead States, 2013). Allowing students to struggle appears to be a good way to stimulate thinking about their actions. During the interview, B6 recognised that he had not made the value of this type of thinking explicit, but immediately thought of a strategy whereby he could have made these connections stronger:

*B6: Just even in little groups. The questions I could have asked that would have linked that. You know, it's a pretty simple question to sort of link in. Obviously the Christchurch re-build [after the recent earthquakes] would be an easy example for that. Do you think these people [re-building Christchurch] are just doing their first idea on whatever they're doing?*

Having come up with one idea, he quickly saw that this type of questioning could be used in a plenary session at the end of the lesson:

*B6: And having asked that on a smaller group, getting them to voice that as a concluding, to say, 'Hey, yours didn't go right, but what did you learn out of that?' And sharing that with the sort of class, in a class situation.*

So the process of lesson observation, detailed feedback and discussion had an immediate effect on B6, as he began to generate his own ideas about how he could improve the delivery of NOS in his classroom. B6 also appreciated ideas and teacher notes accompanying this lesson:

*B6: Yeh, It was really good to have that written there ... just to reinforce that your, sort of, you know your idea of nature of science, and the ideas linked with this lesson ... sort of reassures you and pushes you to do it a lot more.*

Although he had read the curriculum document, it was clear that he wanted guidance at the level of individual lessons or experiments rather than general statements which he was not sure how to turn into classroom teaching strategies:

*B6: The fact that it was so lesson specific was really, um, refreshing. And less time, sort of, pondering on all these sort of things that for me is still a learning process. And reinforcing that you're kind of on the right track with your train of thought is always nice. You know, if you're planning 20 lessons a week to sort of, include those [NOS] elements in it.*

So, the work load that B6 had to cope with meant that he was not prepared to put extra time into planning the inclusion of NOS ideas into his lessons. However, if lesson plans and teaching strategies were provided, he was willing to try them, and if they worked to improve engagement and understanding, as in this lesson, it would seem he would be likely to try them again.

The resources provided for teachers must therefore be of good quality, well tested, and deliver the outcomes expected in classrooms. It is not only the teachers that need to practice delivering NOS ideas, but those providing resources must observe them in action, assess their effectiveness and improve them accordingly. The difficulties in producing good resources have long been recognised, with Allchin (1997) showing how effective good resources can be for delivering NOS ideas, but also how much time and effort was needed to produce quality materials.

### **6.2.7 Analysis of lesson taught by P2 on sound**

Date: June 2014      Audio recording made of the lesson and interviews.  
Interviews with teacher P2 and students Z1 and Z2.

The day before this lesson, teacher P2 had asked me to go over the lesson plan with him and discuss how he could deliver some NOS ideas, as he was unsure of exactly what to do, but was keen to try delivering more NOS in his class. We talked over the inclusion of observations, especially mentioning that these often begin the scientific process. I suggested starting with the observations, offer explanations for them, and then test these by experiment. Then use these new observations to evaluate the explanation or theory until enough evidence has been accumulated to convince people that the explanation is valid. At the same time as doing this in class, keep linking the process to how real scientists work so that the students see that they are

modelling the way science is actually carried out. During the interview following the lesson, P2 acknowledged that he had changed the way he taught as a result of this discussion:

*P2: You want me to be honest right? If we hadn't had that discussion I would just teach it the way that I usually teach. And I do do lots of experiments and I do ask them these questions. But if we hadn't had that discussion I wouldn't even have mentioned scientists or that this method, or even observation, and all those words. So it did make a lot of difference.*

Lesson objectives: Describe what sound is

Describe how the speed of vibration (i.e. frequency) affects the sound

Lesson summary:

The lesson started with some revision of the parts of the eye, which had been covered the previous day. Students then wrote down the learning objectives and P1 demonstrated, and involved students in a range of experiments related to sound, which included in sequence:

Feeling their own voice box while making sounds.

Touching a speaker cone to feel the vibrations while it produced a sound.

Using a tuning fork to produce a sound then touching it to their lips.

Rubbing the rim of a glass bowl to produce sound.

Watching a speaker cone to see it vibrating when sound is produced.

Putting a ringing tuning fork into water to see the splashes produced.

Watching a video clip of air being removed from a bell jar with a ringing bell inside.

During all these activities, P2 kept asking the students to explain their observations, to predict what would happen in the next experiment, and if they were convinced by the explanations offered.

### 6.2.7.1 NOS themes observed

#### a) Empirical NOS

There were many opportunities to make observations during this lesson, and students were encouraged to carefully observe using three different senses, hearing, sight and touch. At the start of the experimental section of the lesson, P2 made the link between observations and the way scientists worked:

*P2: So here we are, let's ask this question. Well let's make some observation, that's what scientists do, right? So sound, I know we can hear it, but what would it feel like?*

This was however, a very brief link to the importance of this NOS concept, which could have been made more explicit by explaining that what they were doing in class models the way science is carried out. As Jarrard (2001) noted, careful observations are the foundations upon which theories are built. That observations are important was stated implicitly many times during the lesson through comments such as:

*P2: So we've made series of different observations, on the things that make sound. And when we felt these things, they all felt the same.... We think they all vibrated.*

The word 'observation' was used twelve times during the lesson, as students were again and again asked to describe what they felt, saw or heard. However, there was only one other occasion during the lesson when the link between making observations and the way science works was made explicit:

*P2: This is a really good science. Like, making observations, and thinking about what we see, or what we feel.*

#### b) Scientific method and critical testing

The process of observing an experiment, offering an explanation or theory, and then

testing this theory was very well illustrated in this lesson. The process was introduced by P2 early in the lesson:

*P2: So we're going to make some observations, we're going to think about it. And we're going to see some more things that will perhaps support what we think sound is.*

As with the comments regarding the use of observations, P2 could have made it explicit to students that this is the way that scientists work, and they are following the same process in class. The class then worked through the first few activities to establish that sound is caused by things vibrating:

*P2: So, it's the same feeling, or similar feeling, that you had when you touched your neck when you're making sound. So, when something makes sound, what is it doing?*

Student: *Vibrating.*

Although at this point the connection between what they were doing and NOS generally was strongly implied, P2 did not explicitly make the point that making theories to explain observations is the way that scientists work. Popper (1959) described this as the deductive method of science, with theories being tested by experiments. So, before going onto the next demonstration, P2 could have asked the students to make a hypothesis about what they thought would happen based on the theory. Students were however, asked if they were convinced by the explanation offered:

*P2: So when something makes sound, it feels like vibrating. So that's our conclusion, or that's what we think sound is. Are we convinced?*

There was mixed response to this question, with many students saying they were convinced while others were not so vocal in their support for the idea. The teacher responded with NOS ideas around the scientific process, suggesting they needed to gather more evidence from different situations to convince people of the current

theory. Again the parallels with the way in which science in general works were not explicitly made:

*P2: Some people still aren't convinced. We are actually going to have a look at, well make more observations, to actually support this idea. But for now, we think that sound is vibrating, vibration.*

The next step would be to make more explicit to students that this is the way that scientists work. As Kuhn (1962) noted, one of the great strengths of science is that scientists have to convince their peers that both their evidence and conclusions are sound. Although P2 did not make the NOS connections explicit to the students, it was clear from the interviews with students that they had gained an understanding of the way in which science and scientists worked:

*Interviewer: What do you think you learned from the lesson about the way that science works? How scientists do things?*

*Z2: Well, I guess they just experiment heaps, with different kind of ways to make sound vibrate. A lot of practicals involved.*

*Interviewer: One of the things that he [the teacher] was saying was, he said a few times during the lesson, you know. Are you convinced? So what do you have to do if you're not convinced?*

*Z2: I dunno, probably just do some more experiments to show, get more evidence, that it actually, that's how it works.*

So Z2 understood the empirical NOS, and that any conclusions have to be based on this empirical evidence which often comes from experiments. Student Z1 too had an awareness that claims had to be justified by experiments, and these must be able to be verified by others:

*Interviewer: And do you think scientists have to convince other people of what they find out?*

Z1: *Yeh, yeh. Cos, or it's just not true at all. ... And we can test it ourselves.*

So by repeating the process of asking questions, collecting evidence and formulating theories, P2 had successfully imparted NOS knowledge to his students, even though this was only briefly mentioned explicitly during the lesson.

#### **6.2.7.2 Signs of engagement**

As noted in my field notes immediately after the lesson observation, all the students seemed fully engaged throughout the lesson. This was particularly impressive as these students were in the designated 'learning support class', indicating that many had reading, writing or learning difficulties, sometimes with social or behavioural problems too. The three types of engagement as defined by Fredericks et al. (2004), behavioural, emotional and cognitive, were all noted during the lesson, as the following observations and subsequent interview extracts show.

Firstly, the behaviour of the students was excellent throughout the lesson, even with multiple changes of activity: from group discussions, to teacher demonstrations, to activities where students did their own experiments. At all times the students were cooperative, moving safely and sensibly around the room and quickly becoming quiet when required. No disruptive behaviour or behaviour associated with disengagement was observed. Thus the NOS approach of putting observation as the focus of the lesson, actively involved the students and appeared to sufficiently engage them so they were keen to participate in all aspects of the lesson.

In terms of emotional engagement, P2 quickly gained the students' attention at the start by presenting the lesson as a puzzle with questions to answer, as these field notes and transcripts describe:

P2: *So, have a look at this. This is what we are going to talk about. The big question is, what is sound? Can you hear it? [positive answers/murmuring from the class] Of course we can hear it, that's why it is sound. But, if you really think about it, what is sound? Have you ever seen a sound? Can you see my voice?*

Student: *No*

P2: *Can you feel my voice?* Some answers/discussion and laughter indicating some interest/engagement in this unusual way of thinking about sound. In response to some answers:

P2: *I know you can hear my voice, but you can't actually feel it. Or you can't, um, touch it. Right. Or you can't see it. You can't even smell it. Can you taste it?*

P2 extends their thinking to the full range of senses. His voice is varied and interesting, as if he was telling a story, building up the introduction to intrigue and entice the reader to find out what happens.

This passage shows how key NOS ideas such as beginning with observations and generating questions to explain them can be very engaging, especially when presented as puzzles to solve. As Sawyer (2006) and Willingham (2009) suggested, solving puzzles brings emotional rewards, especially if the teacher is able to guide students to find the solutions for themselves.

Other signs of emotional engagement came from comments made by the students at various times during the lesson, such as "*It was cool*", from one girl after she had felt the tuning fork vibrating. There were obvious signs of amazement from the students, often accompanied by laughter, as they were surprised by observations such as the glass bowls 'singing', or the water splashing when a tuning fork was immersed. During the interviews, the students' obvious enjoyment and sense of fun when doing experiments and activities was probed further:

Z2: *It was just, like, fun to, like, listen to noises.*

Interviewer: *So you think you do learn by doing experiments? Do they help you learn what he's [the teacher] trying to get over? Are they just fun, or do you actually learn?*

*Z2: I learn, 'cos I enjoy it so it just helps me learn if I enjoy what I'm doing. It's easier to learn.*

The link between students' enjoyment of science lessons and improved learning outcomes has been noted by Ebenezer and Zoller (1993), with Pugh et al. (2010) linking the increased enjoyment that flows from enjoyment to conceptual change and deeper understanding.

### **6.2.7.3 Issues related to the delivery of NOS in the classroom**

Although the lesson was delivered using NOS principles, these were not always made explicit, even though teacher P2 had gone through the process of thinking about NOS by completing the VNOS survey and interview, and had discussed how to introduce NOS ideas before the lesson. As Bartos and Lederman (2014) noted, it is not easy for teachers to weave together science content, NOS and SI, even when they have sound NOS knowledge. The lesson observation for P2 once again highlighted the considerable support and professional development needed even for teachers who are keen to deliver NOS.

The lesson observation and feedback were clearly useful for P2 to identify areas of NOS delivery on which he could improve:

*Interviewer: As noted in the lesson write-up, there were several opportunities to link the 'methodology' you were taking them through, more explicitly to the way science works. Were you aware that stronger links could be made?*

*P2: Not during the lesson, but after, when I was reading through the summary of the lesson, I could actually see, I could remember and go back and say, oh that, or those were the moments I could make the link more explicit, I could improve, add more stuff to it. Not during the lesson, but I can see now.*

However, the lesson did cover some NOS themes very well, with P2 clearly making an effort to incorporate the ideas discussed before the lesson. He described during the interview how he felt about the lesson:

*P2: I felt funny throughout the lesson, because at first I constantly reminded myself to use all these terms and make the link, make the link, and, er, and what-not. But throughout the lesson it came a bit more naturally. It was only a 50 minutes lesson, but about half way through I was actually, I was getting used to the method saying: Right, so are you convinced this, we making observations, and do we need more evidence to convince you or other people? And then it just came naturally.*

Interviewer: *So you haven't used those terms [before] ...*

*P2: It was something very, quite new to my teaching.*

I noted that the techniques used seemed to engage the students, a view which was supported up by the student interviews. P2 felt that this particular lesson was well suited to incorporating NOS, but maybe it would be different with other lessons:

*P2: But for this particular lesson I felt it was quite successful, and I enjoyed teaching, and I enjoyed using these method, rather than just giving them the facts.*

So, by trying this new strategy of questioning and building knowledge through a NOS perspective, P2 could see and feel that it was effective during the lesson. The need for teachers to feel that using NOS in class is worthwhile is vital, as it should encourage them to keep using these strategies, and help others adopt them too as they hear about the effectiveness of NOS. As Harland and Kinder (1997) noted, teachers will only change their practice if they see value in the new approach. These ideas were clear to P2 as he thought about how he would approach his lessons in the future:

*P2: It's going to take some time and effort, but I can definitely see the benefit of incorporating nature of science, in terms of engaging students. And also preparing them to become real scientists later on. Even when they don't become scientists, all these skills can be very useful in many areas.*

However, the perennial fear experienced by many teachers was also expressed by P2 as he described another lesson with this class, when they were discussing facts about

the earth as part of the topic on Space. The students were keen to question how we knew these facts were true, and P2 had led a lively discussion from a NOS perspective, encouraging argument and debate:

*P2: I actually enjoyed having all these discussions during the lesson, but another thing that was constantly stuck at the back of my mind was ... I couldn't even get through half of what I was planned to teach, because we were all fired up in these discussions. Which is a good thing, holistically looking. We are doing real science, which is enjoyable, they are learning, and that's a fantastic (sic). But again, at the end of the day, they're not going to do well in the test.*

This need to cover the content in order to be ready for the test is often given as a barrier to the inclusion of NOS (Dhingra, 2003; Bartholomew et al., 2004), and is a legitimate concern which has to be addressed if teachers are to incorporate NOS regularly in their lessons.

The final point raised by P2 related to problems implementing NOS in his classes, concerned the need for specific resources and strategies. He was aware of NOS objectives in the New Zealand curriculum, and that these were translated into our own school teaching schemes, but even when these NOS ideas were stated, there were significant barriers to delivering NOS in his classroom:

*Interviewer: So if there were to be nature of science things included, they'd have to be in the local teaching schemes. Do you read those?*

*P2: I will read it. But I don't know, my immediate reaction. If we hadn't gone through this process, and if just someone gave me the document, and say this is what you have to do. I would find it, I would have found it pretty daunting. Because it would feel like just an extra work that I have to do on top of what I'm already doing.*

At this point, P2 was shown an example of the experiments written for the Year 9 chemistry unit, complete with teacher notes and suggestions for ways of including NOS ideas. His response was clear:

*P2: That'd be very useful. if these were written for all units, I would certainly go through them, and use most of them, if not all.*

He agreed that these specific NOS prompts and questions for the teacher to ask were more useful than general statements in the curriculum document or school scheme. P2 could see that even if one unit was done like this, then teachers could try it, see what worked and apply the successful strategies in other units:

*P2: I think it is the examples that the teachers need. I had a really good lesson which has given me a really good example, and I also know what I can improve on. I can just go from here, but it's just having that experience.*

### **6.2.8 Summary of lesson observation analysis**

The lesson observations provided valuable information to help address parts of all three of the research questions, as stated in Section 1.4. The observations provided direct evidence of NOS being delivered in every lesson, with the audio recordings and field notes providing the detail, enabling judgements to be made about the students' level and type of engagement. The interviews were then crucial to check these judgements and explore the reasons for the students' engagement in the lessons. Finally, the interviews also allowed questions to be asked of both teachers and students, concerning issues beyond the immediate lesson, which revealed much about the benefits and problems related to NOS across the Year 9 programme.

#### **6.2.8.1 NOS themes observed**

The lesson observations recorded and analysed, involved ten different teachers over twelve lessons and therefore can only be regarded as a small sample of the overall delivery of science at the school. However, even given this small sample, it is clear from Tables 6.1, 6.2 and 6.3 that almost all the NOS themes and New Zealand NOS curriculum objectives (Ministry of Education (2007b) were covered to some extent in these lessons. It would seem reasonable to extrapolate that over the course of the whole year, most of these NOS concepts would be covered many times.

Table 6.1

*NOS themes noted in lesson observations for each teacher*

<b>NOS</b>	<b>Teachers observed with NOS theme in lesson</b>
Tentative	B2, C1
Empirically based	B2, B3, P1, B1 (second year), B6, P2, B5
Scientific method and critical testing	B2, B3, P1, B1 (second year), B6, P2, C1, B5
Subjective/theory laden	None
Creativity and imagination	B7
Socially/culturally embedded	B1 (first year), B6
Observation v inference	B1 (first year), B2, P1, B1 (second year)
Theories v Laws	None
Argumentation	B7, B2, B3, P1, B1 (second year), B6, B5
Cooperation	B7, B6, C1

There were two clear gaps in the delivery of NOS themes as shown in Table 6.1, with no reference seen in lessons to the difference between theories and laws, or that scientists bring their own subjective views and knowledge to problems. As neither of these ideas appear in the New Zealand curriculum (Ministry of Education, 2007a), this is not a surprising finding.

The analyses of the lesson observations therefore suggest that a significant amount of NOS was being taught, but mostly implicitly, which the research literature indicates is the norm (Lederman & Lederman, 2014). However, many of the lessons observed were delivered with an overall NOS approach: that is, the structure of the lesson was based around questioning, experimentation and argumentation. In this sense, NOS was being used as the overarching strand to deliver the curriculum, although it was clear from the interviews with teachers that they rarely planned to include specific NOS objectives in their lessons.

Table 6.2

*NOS objectives from Level 3 and 4 of the New Zealand curriculum noted in lesson observations*

<b>Curriculum statement</b>	<b>Teacher observed with NOS objective in lesson</b>
Appreciate that science is a way of explaining the world and that science knowledge changes over time.	B3, B6, P2, C1, B5
Identify ways in which scientists work together and provide evidence to support their ideas.	P1, B1, B6, P2, C1, B5
Build on prior experiences, working together to share and examine their own and others' knowledge.	B7, B3, P1, B1, B6, P2, C1, B5
Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations.	B7, B3, P1, B1, B6, P2, C1, B5
Begin to use a range of scientific symbols, conventions, and vocabulary.	All teachers
Engage with a range of science texts and begin to question the purposes for which these texts are constructed.	B7
Use their growing science knowledge when considering issues of concern to them.	B7
Explore various aspects of an issue and make decisions about possible actions.	B7

Table 6.3

*NOS objectives from Level 5 and 6 of the New Zealand curriculum noted in lesson observations*

<b>Curriculum statement</b>	<b>Teacher observed with NOS objective in lesson</b>
Understand that scientists' investigations are informed by current scientific theories and aim to collect evidence that will be interpreted through processes of logical argument.	B7, B3, P1, B1, B6, P2, C1, B5
Develop and carry out more complex investigations, including using models.	B3, P1, B1, P2, B5
Show an increasing awareness of the complexity of working scientifically, including recognition of multiple variables.	B3, B5
Begin to evaluate the suitability of the investigative methods chosen.	B3, P1, B1, B6, C1, B5
Use a wider range of science vocabulary, symbols, and conventions.	All teachers
Apply their understandings of science to evaluate both popular and scientific texts (including visual and numerical literacy).	B7
Develop an understanding of socioscientific issues by gathering relevant scientific information in order to draw evidence-based conclusions and to take action where appropriate.	B7, B1

More explicit planning and delivery of NOS did occur when teachers used the experiments written with specific NOS prompts and teacher notes, or when discussions were had before the lesson on how to include NOS. Even then, teachers rarely made explicit the link between the activity the students were doing and the way science or scientists work.

### **6.2.8.2 Strategies used to deliver NOS and signs of engagement**

A wide range of strategies to deliver NOS were used during the lessons observed, with a summary of those focussed on specific NOS themes shown in Appendix G. In every lesson, some aspect of NOS was evident, although usually delivered implicitly. The most common activity observed was for the students to carry out some form of experiment or practical investigation, with every teacher except B7 using this strategy. Carrying out experiments appeared to a very effective way of delivering NOS and engaging students.

The observations of students in class and the subsequent interviews revealed that many students gained much more from experiments than simply having fun and a break from writing. They provided evidence that using a NOS approach to present science as an empirical process produced much deeper engagement. Students consistently expressed delight and surprise over many of their observations, indicating emotional engagement, even when the experiment was as simple as evaporating salt water, or watching two liquids dissolve into each other. The joy of seeing the results of experiments went further for some students who noted the satisfaction they gained in confirming science concepts for themselves. Cognitive engagement came from reflecting upon the experiments students had performed, often through teacher questioning.

Whether or not the NOS themes were being made explicit, it appeared that students were highly engaged when teachers used a NOS approach. Not only could this engagement be seen and heard in the lessons and subsequent interviews, but there were indications that the engagement led to increased understanding and retention of science concepts.

### 6.2.8.3 Issues related to the delivery of NOS in the classroom

The biggest issue concerning the delivery of NOS was the lack of an explicit approach, with most teachers having no clear NOS learning objective in mind when they planned their lessons. In contrast, there was always an objective made clear to the students regarding science content. Hattie (2009), argued that making the learning intentions clear in every lesson was one of the key aspects required for effective teaching and learning, while the need to make the NOS outcomes explicit has been stated as essential for the effective delivery of NOS (Lederman, 2007).

Other areas identified as problems for teachers included:

- Relinquishing some control in order for students to experience genuine open-ended investigations.
- Accessing good quality resources which illustrate specific NOS themes.
- Limited time for teachers to develop and trial their own NOS activities.
- Managing all the equipment and resources needed to make lessons run smoothly. It is crucial that everything works well when teachers are trying new strategies.
- Lack of PCK for NOS. Teachers need to build their confidence to deliver NOS by trialling good quality materials in a supportive environment.
- Concerns over covering the science content required for assessments.

The majority of these problems were previously identified by teachers during the VNOS interviews, as summarised in Table 5.12. This is a good example of effective triangulation, with different data sources revealing the same problems.

All the problems which the teachers experienced when trying to deliver NOS require personal support and guidance to address. It is clear that simply describing some NOS objectives in a curriculum document will not result in effective teaching of NOS in the classroom. Teachers had only the vaguest notions of what the curriculum required, although they had good knowledge and understanding of NOS themselves. In planning their lessons, they used the schemes and resources provided by the school, or for the longer serving teachers, delivered the lesson as they had always done. The school scheme for each unit did have the curriculum objectives included,

but even these did not provide enough guidance for teachers to confidently include NOS themes in their lessons. The most successful inclusion of NOS came when resources were used with NOS themes made explicit in the supporting teacher notes for a particular experiment, or when discussions were had before the lesson about how to include NOS themes.

The whole process of observing lessons, giving feedback and individual support through the interviews seemed to be an effective way of producing change in teacher practice. Once pointed out, they could see that relatively small changes in their teaching could bring in NOS themes explicitly and effectively. Most teachers were enthusiastic about making these changes.

### **6.3 Other data sources**

#### **6.3.1 Student feedback surveys**

As part of regular practice at the school, teachers were encouraged to survey students about their lessons and learning, and reflect on the feedback given. The aim was to ensure that teachers were delivering lessons pitched at the right level of difficulty for their students. One part of the feedback surveys relevant to the engagement of students related to their enjoyment of lessons, with results from two classes shown in Tables 6.4 and 6.5.

The data shows that the majority of students enjoyed their science lessons, which supported the TOSRA data. In order to gain more information about what aspects of the lessons were most or least enjoyable, students had the opportunity in these topic feedback forms to write their own comments. The overwhelming majority of these comments were positive and referred to experimental or practical work as being enjoyable, again reflecting the comments made by students in the TOSRA surveys.

Table 6.4

Number of student responses in feedback surveys for four topics in P2's class 9Q in 2013 to the item: *The unit of work was ...*

Unit of work was:	Alchemy	Space	Food or Fuel	Fabulous Fragrances
Enjoyable	8	7	5	4
OK	6	5	4	7
Not very interesting	0	1	1	1
Boring	1	1	0	1

Table 6.5

Number of student responses to three feedback surveys in B5's class 9C in 2014 to the item: *I enjoyed learning in most of the lessons.*

Topics	strongly agree	agree	neither agree nor disagree	disagree	strongly disagree
Introductory unit and Plants	3	14	4	0	0
Energy for Life	3	18	4	0	0
Radiation and the Body	5	15	6	0	0

For example, in teacher P2's class 9Q, of the twenty-three comments made, eighteen were positive, including these:

*it was fun doing the chemical reactions*

*the teacher is nice and the experiments exciting*

These comments indicate emotional engagement with the activities. Some students were able to give more insight into why they found the experimental work enjoyable, as this comment from a student in 9C showed:

*i enjoyed the chemical tests: testing for starch, lipids ect. a hands-on activity like that is very useful to learning and helping me understand*

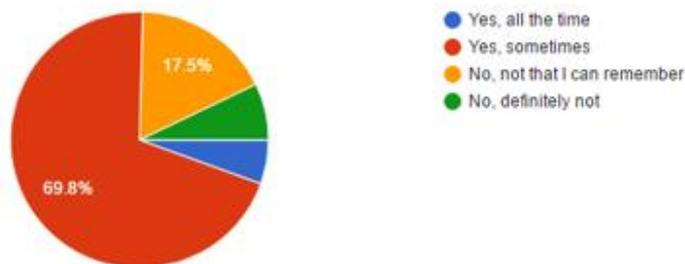
This indicated both emotional and cognitive engagement, as the student appeared to gain satisfaction from the deeper understanding resulting from the activity. These comments are very similar to the ones made by students in the interviews related to the TOSRA surveys and lesson observations. Thus the NOS approach used by P2 and B5 seems to have been engaging the students, and appears to have been carried out over the whole year.

Although the results from the feedback surveys appear to support the findings in other parts of this research project, they must be treated with some caution. The results from P2 and B5's classes have been used as they were the most complete record of the year offered by the teachers involved. There was no systematic collection of this data as part of the project; teachers were simply invited to send me their feedback results. It could be that only those teachers who had positive survey results passed them on, although my impression at the time was that this was not the case.

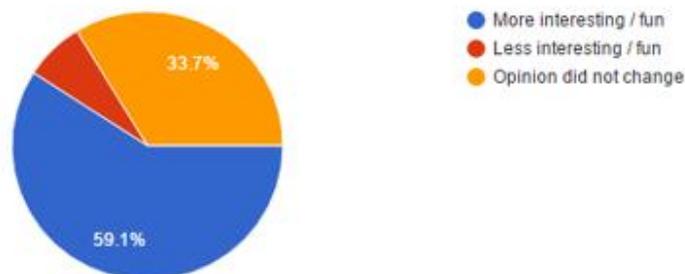
Partly to check whether teachers were only reporting positive data and partly to get a broader view of student perceptions about their experiences in science, I conducted a survey of more classes and teachers at the end of 2015. This common survey was completed by 252 of the 401 students in the Year 9 cohort, coming from eleven of the fifteen classes. Some of the data relevant to this research is shown in Figure 6.6. The results show that the majority of students gained a more favourable impression of science as a result of their year in school science classes, and an even larger proportion were sufficiently engaged to talk about their experiences outside of class. Students were also invited to complete the sentence "This year science was, ...." with a one word answer, with the top three responses being 'interesting' (77 students), 'fun' (32) and 'good' (22). The most negative response was 'boring', which was written by only ten students. Thus this wider survey appeared to support the data from the individual topic surveys and from the TOSRA data, indicating that the majority of students enjoyed their science lessons and were emotionally and cognitively engaged.

Did you talk about what you were learning in Science with family at home or friends?

(252 responses)



Compared to the start of the year, I now think Science is... (252 responses)



*Figure 6.6*

Feedback from Year 9 students at the end of 2015 concerning their experiences in science classes over the whole year.

### 6.3.2 Senior science subject choice data

One of the major concerns around the world, and a reason given for curriculum change to include NOS, has been the decline in the number of students choosing to take science subjects in senior secondary school and onto tertiary level (Hipkins, 2012; Osborne et al., 2003b; Tytler et al., 2008). While there are many factors that influence student's subject choices, including the economic situation at the time, Tytler et al. (2008) noted that most students have a good idea of their career pathways by the end of Junior High School. They specifically recommended targeting student engagement in science in early secondary school in order to encourage students to at least consider senior science options.

The data shown in Table 6.6 shows that students have been choosing senior science subjects in increasing numbers since the introduction of the new science curriculum in 2010. This year also marked the start of the research project which is the subject of this thesis, the progress of which is outlined in Figure 4.1. This timeline shows that the introduction of NOS ideas into teaching schemes began in 2011, with the school-wide science fair starting in 2012.

Table 6.6

*The number of students taking science subjects at the school involved in the case study from 2010 to 2016*

	2010	2014	2015	2016	% change 2010 to 2016
School roll	1685	1762	1851	1866	+10.7
Compulsory science roll (Year 9, 10, 11 students)	1067	1145	1204	1224	+14.7
Optional science roll (Year 12 and 13 students)	546	767	788	843	+54.4

The majority of the VNOS surveys and interviews also took place in 2012, thus raising the awareness and importance of NOS in the minds of all science staff. Thus students exposed to an increased NOS approach in 2011 and 2012 were the group opting for senior sciences in 2014 and 2015. While no direct correlation can be made between the introduction of NOS and the increased numbers taking senior subjects, it is at least clear that there has been no adverse effect. Whatever the other factors involved, the data from the TOSRA survey, lesson observations and interviews indicates that students were engaged by a NOS approach in their science lessons, while the subject choice information shows students choosing senior sciences in record numbers for this school.

### 6.3.3 Examination results

In New Zealand, as in most other countries, students sit examinations at the end of each year, the results of which are highly significant for the students and teachers. Students need good results to keep career pathways open and teachers are judged on the performance of their students. The examinations for Year 11, 12 and 13 students in New Zealand focus primarily on traditional science content, with little emphasis on NOS, so if teachers are to be persuaded to deliver NOS in their classes, they must be convinced at the very least, that a NOS approach will not disadvantage their students in these examinations. As Harland and Kinder (1997) argued, teachers must personally value any proposed change before there is any chance of them making a change in their teaching practice.

In this case study, the teachers were persuaded to try and deliver NOS in Year 9 and 10 classes, and this did require some pruning of content to allow for the inclusion of the school Science Fair, and more time for in class investigations and discussions. Thus it was important for data to be collected to see if the changes in the Junior school programme had any effect on the students' performance in examinations in subsequent years. The results for students in Year 11 Science and Year 13 Physics are summarised in Tables 6.7 and 6.8 respectively, and show a decrease in the percentage of Not Achieved grades, or put more positively, an increase in the percentage of students passing the examinations.

The results for Year 11 Science are significant because success here allows students to choose senior science subjects, such as Physics. The Physics results are shown, as this is the science discipline that experienced the most change in the reorganisation of topics in the Junior school, to allow for more NOS. For example, the Light topic was changed to Radiation and the Body, replacing a more traditional approach focused on the properties and behaviour of light, to a more contextual, NOS approach focussed on the effect of all forms of radiation on humans.

Table 6.7

*External examination results for Year 11 students at the school the focus of this case study*

Percentage of students attaining each grade					
Year of examination	Total number of science papers taken	Not achieved	Achieved	Merit	Excellence
2013	609	24	31	31	14
2014	546	18	33	31	18
2015	816	14	38	31	17

Table 6.8

*External examination results for Year 13 Physics students at the school the focus of this study*

Percentage of students attaining each grade					
Year of examination	Total number of physics papers taken	Not achieved	Achieved	Merit	Excellence
2013	142	22	47	22	9
2014	149	21	42	28	9
2015	198	7	37	40	16

Whatever the arguments and justifications for the inclusion of NOS in science lessons, the examination results from this school suggest that students are not disadvantaged by making time to include NOS themes in Year 9 and 10. As with the increase in students choosing science subjects, no direct link can be made between NOS teaching and improved examination results. However, at least teachers at this school can be confident that their efforts have not adversely affected their students' performance in these high-stakes assessments.

#### **6.4 Chapter summary**

A large amount of data was collected over the course of this research project: VNOS surveys and interviews with eighteen staff; four TOSRA surveys of over 200 students; and interviews with eleven teachers and twenty students regarding the TOSRA data. This was followed by direct observation of twelve science lessons, and subsequent interviews with each teacher, along with thirteen of the students in those lessons. The intention was to gather enough information to produce the rich descriptions required to give credibility to the conclusions drawn, as suggested by Guba and Lincoln (1989), and Tracey (2010). These conclusions are discussed in Chapter 7, where detailed responses to the key research questions are given and recommendations for future actions and research proposed

## **CHAPTER 7 Conclusion**

### **7.1 Introduction**

The conclusions from this research project are summarised first, by specifically addressing the three research questions presented in Chapter 1. The implications of these conclusions and recommendations based on the findings are then presented in Section 6.3, while the limitations of this study are addressed in Section 6.4. Finally, some proposals for further research are discussed and comments made about how NOS could be promoted to teachers and implemented in schools.

### **7.2 Response to Research Questions**

#### **7.2.1 Research Question 1: How effective is the Nature of Science strand in the NZ science curriculum in terms of engaging Year 9 students in a New Zealand high school science programme?**

In answering this question, a distinction has to be made between the NOS strand in the NZ curriculum and NOS as understood by the teachers involved in the research. As discussed in Chapter 2, there are many opinions as to what exactly constitutes NOS, although there is a general consensus concerning the key aspects of NOS that should be taught in schools. The NZ science curriculum incorporates both a broad understanding of NOS that fits with this consensus as part of the learning area description for science (Ministry of Education, 2007a), and more specific learning objectives (Ministry of Education, 2007b) for each Year level, which do not match this consensus so tightly. Regardless of this confusion, it was clear from this research, particularly the VNOS interviews, that most of the teachers did not get their understanding about NOS from the curriculum, but from personal experience and exposure to science ideas through their own education and training. Thus research Question one was approached using the intent of the NZ curriculum NOS strand rather than from the specified learning objectives.

Given this approach, the evidence from all data sources in this research project indicated that incorporating NOS was effective in engaging students in science

lessons. Students were consistently well behaved and enjoyed activities such as experiments, with the NOS elements that teachers included stimulating emotional and cognitive engagement. The interview data supported these findings with both teachers and students perceiving the inclusion of NOS themes as contributing to increased engagement in science lessons.

### **7.2.2 Research Question 1a: What are teachers' perceptions of the effectiveness of the Nature of Science strand in terms of engaging Year 9 students in high school science classes?**

The evidence for the teachers' perceptions of the effectiveness of NOS in engaging students came from all three interview processes: discussing their responses to the VNOS survey; following up lesson observations; and investigating the TOSRA results for their classes. The importance of using this sort of triangulation (Lincoln & Guba, 1986; Mathison, 1988; Tracey, 2010), has been identified as crucial for the construction of valid conclusions. In this study, all three of the interview processes revealed that teachers did perceive the inclusion of NOS ideas and strategies as beneficial to improving the engagement of students in their classes, although common problems such as a lack of suitable resources were also reported.

The VNOS interviews involved the greatest number of science staff, eighteen in all, and detailed analysis of the nine teachers whose lessons were subsequently observed is provided in Chapter 5. The first point to emerge from both the VNOS survey and interviews was that the teachers did have a good understanding of the NOS themes and they agreed with these as the basis for explaining the way science works. The second point was that all of the teachers could give an example of a teaching strategy they had used to deliver NOS, although most of these did not involve making the NOS link explicit to students. When discussing these strategies, many teachers noted that they did improve the engagement of students, for example, they described the enjoyment and excitement of students when teachers structured lessons to include argumentation through guided questioning.

Having established that the teachers had a good understanding of NOS and had all used some strategies to deliver NOS ideas, they were then asked directly if they felt

that teaching with a NOS approach affected student engagement. The teachers all agreed that a NOS approach did increase engagement, indicating both emotional and cognitive engagement when describing the satisfaction students gained from understanding concepts through carrying out experiments, or having them linked to real world applications. However, another common theme emerged which centred on the problems related to the actual delivery of NOS in the classroom. The main problems identified were a lack of resources and professional development opportunities, combined with time pressures, resulting in NOS being left out of lesson planning.

The lesson observations then provided an opportunity to examine the perceptions of nine teachers' regarding NOS, in response to specific actions they had taken in their classes. The teachers had the NOS elements of their lessons explicitly highlighted, through the written feedback given, and were able to immediately reflect on their impact on student engagement. When examined in this light, the teachers all agreed that their NOS approaches were engaging for students. These views were reinforced when they were also presented with comments and insights from students in their lessons whom I had interviewed. Quotes showing the students being excited or fascinated by often seemingly trivial aspects of an experiment, such as an unexpected observation, added a new dimension to the teachers' impressions of student engagement in their classes'.

However, the teachers also acknowledged that their use of NOS themes was mostly done implicitly in their classes. After reflecting upon the lesson observation reports and through discussions during the interviews, they could see that the NOS themes could easily be made more explicit, simply by using the vocabulary associated with NOS, and making direct links between the activities in class and the way scientists work. For example, teacher B1 used the terms observation and inference explicitly with her classes for the rest of the year, and teacher B7 could see that linking the cooperation and collaboration she expected in class to the way scientists work would add another, deeper level of engagement for her students.

The interviews with teachers concerning the TOSRA results for their classes also provided an opportunity for them to reflect on the effect of using NOS strategies over

the whole year. Several teachers commented on the Science Fair as being a positive, engaging experience for students, even some who seemed disengaged during regular lessons. Through discussion during the interviews, teachers came to realise that the Science Fair process was a great opportunity for both teachers and students to experience the way NOS can be delivered in a school setting. Some teachers were so impressed with the engagement of students during this process that they altered their teaching to try and include more open-ended and challenging experiments in their regular lessons. Other teachers recognised the value of the Science Fair process but came to appreciate that students needed more support and guidance in order to maintain their engagement and achieve successful outcomes.

Finally, in the second year of data collection, the second research question was put directly to the six teachers interviewed as part of the follow-up to the TOSRA surveys. As shown in Table 5.21, they all shared the perception that using a NOS approach engaged their students. Thus all forms of evidence collected reinforced the conclusion that the teachers did perceive that including NOS was engaging for students in their classes.

### **7.2.3 Research Question 1b: What are Year 9 students' perceptions of the effectiveness of the Nature of Science strand in terms of engaging them in high school science classes?**

One of the key findings from the lesson observations was that although teachers did use a NOS approach in their lessons, there was very little explicit mention of NOS themes and no use of the term 'nature of science' itself. Therefore, any conclusions about the role of NOS in engaging students are made from the initial assumption that students did experience teaching using a NOS approach, but were not necessarily aware that they had been exposed to NOS thinking. For example, when students were asked to carefully record experimental observations, or discuss their results, the teachers were illustrating the NOS themes of observation versus inference and argumentation, but the idea that these processes were crucial to the way that science works was not made explicit to the students.

Investigating student's perceptions of the effect of a NOS approach in science classes was done primarily through the interviews with students following lesson observations, although some insights were gained by asking students during the lessons about their feelings towards the activities in which they were engaged. The strong conclusion was that students were engaged by the strategies used by teachers to deliver NOS themes. Although conducting experiments was perceived as more enjoyable than simply writing, the levels of emotional and cognitive engagement were significantly increased when NOS themes such as the importance of good observations, or critical thinking about the experimental method were included.

Similarly, when students were asked to make hypotheses, or given a chance to design their own methods, or even carry out their own investigations, their levels of excitement and interest were raised. Students were also clearly engaged when they were asked to work and cooperate in groups and then discuss and defend their findings. All these strategies model the way science actually works and even if students were not explicitly aware that they were experiencing NOS, they certainly indicated they enjoyed the activities and the increased depth of thinking that many of these approaches required.

Another source of evidence regarding students' perceptions about their science lessons came from the TOSRA data. This gave an indication of the students' level of engagement in their science lessons over the whole year. The survey data indicated that the majority of students enjoyed and valued their science lessons, thus implying both emotional and cognitive engagement. Students were particularly positive about experiments, which was best represented in the TOSRA category *Attitudes toward scientific inquiry*, with over seventy-five per cent of students in both years indicating a positive attitude. This high level of appreciation for experiments, was reinforced by student comments at the end of the survey and by the interviews with students. These interviews revealed that students not only enjoyed experiments but felt they learned a great deal from them. For example, several students commented that through direct observations during experiments, they were better able to understand the theories being taught. Thus when teachers emphasised the need for good observations and the empirical NOS, this helped students grasp the science concepts involved, increasing their engagement.

#### **7.2.4 Research Question 2: What teaching strategies are being used to deliver the Nature of Science to Year 9 students and what impact do these NOS strategies have on student engagement?**

A wide range of teaching strategies were revealed from all of the data sources, although as previously noted, the NOS themes were not usually made explicit. During the interviews concerning the VNOS surveys, for example, all eighteen teachers described the use of at least one strategy for delivering NOS, and clearly thought these had a positive impact on student engagement.

The TOSRA surveys revealed that students particularly enjoyed experiments, with both emotional and cognitive engagement related to these becoming apparent in student interviews. As Ebenezer and Zoller (1993) and Abrahams and Reiss (2012) noted, simply carrying out experiments by following a set of instructions is not engaging for students. Deeper engagement comes when students realise what they are learning is useful to them, or as Skinner and Pitzer (2012) put it, satisfies their need for relatedness, competency and autonomy. The inclusion of NOS themes and thinking appears to give experimental work more significance, and hence increases student engagement.

The importance of the empirical NOS was noted by many students as contributing to their engagement, as they both enjoyed making observations themselves, and appreciated the deeper understanding about scientific concepts they gained through experiments. The use of the Science Fair as a way of both engaging students and delivering NOS themes, was mentioned by several students and teachers. This extended experimental activity allowed NOS themes such as scientific method and critical testing, cooperation and collaboration, and creativity to be discussed more explicitly by teachers than many described in their regular lessons.

Other strategies noted from the TOSRA data included: the use of video clips to show science beyond the classroom; modelling the way scientists work; making connections between science and society; and encouraging questioning and debate in class discussions. All of these strategies included NOS elements, and were reported by both teachers and students as engaging. The strategies that emerged from the

TOSRA interviews closely matched the five key strategies as identified in the literature for both delivering NOS and increasing engagement (see Appendix K). The first of these, creating a supportive learning environment, seemed to be particularly important, a prerequisite for the other strategies to be effective, a point noted by Olitsky and Milne (2012). If students had poor relationships, with the teacher or each other, they generally reported less enjoyment or engagement with science lessons.

These findings were supported by the lesson observations, although in all cases classroom environments were very positive, so there was no opportunity to see the effects of poor relationships directly. Strategies for delivering NOS themes were noted in every lesson observed, as described in Section 6.2 and Appendix G. The most common strategy used required students to carry out an experiment, and these produced high levels of engagement, with evidence supporting this conclusion coming from direct observations and the interviews with students and teachers. In the lessons observed, experimental work was used in a variety of ways which both illustrated NOS themes and increased engagement. This work included:

- Requiring students to make detailed observations
- Organising students to work cooperatively in groups
- Requiring students to discuss their findings with each other and justify them to the whole class
- Questioning students to stimulate their thinking about experimental design, reliability of data and links to theory
- Requiring students to make hypotheses before the experiment and to examine these after they had collected their results
- Giving students choice in how the experiment was conducted
- Presenting experiments as ways of solving puzzles or challenges

The wide range of strategies available within an experimental setting allowed different aspects of NOS to be emphasised, according to the planning and priorities of the teacher. For example, the cooperative NOS might have been a focus one week, with the importance of observations verses inferences emphasised the next.

Finally, the supplementary data collected also appears to support the view that teaching with a NOS approach increases student engagement. The feedback surveys from individual teachers and the Year 9 cohort survey from 2015 indicated that students were both enjoying their experiences in science classes, and becoming cognitively engaged. The increased number of students opting for senior science subjects also suggests that the strategies used in Year 9 classes were effective in increasing engagement with science, although this is an area that merits further in-depth research, as suggested in Section 7.3.

### **7.2.5 Research Question 3: What are the teachers' views of NOS, and have they changed as a result of implementing a new curriculum?**

One way of examining teachers' views concerning NOS is to find out their depth of understanding concerning various NOS themes. Another interpretation is to find out how much they value these concepts and whether they think it is worth teaching NOS in their classes. These two sides of the same question are clearly linked, with research (Lederman & Lederman, 2014; Spiller & Hipkins, 2013) suggesting that even if teachers have a good understanding of NOS concepts, they do not necessarily deliver these ideas in their lessons. Thus research Question three was designed to examine this link, first establishing the teachers' views or understanding about NOS and then gathering evidence to see if these views translated into classroom practice.

The VNOS survey was used to discover the teachers' views of NOS, and these views were probed further during the interviews. The results indicated that all the teachers had a good understanding of most NOS themes, and that their views were consistent over a range of situations and contexts. These views had developed in different ways, ranging from the influence of parents and teachers, to direct experience with post-graduate scientific research.

These views had not necessarily changed as a result of implementing the new curriculum as they already seemed to be well formed before they entered teaching. However, there was confusion around what exactly NOS was, as described in the curriculum. The process of completing the VNOS survey, and discussing the various NOS themes during the interview helped the teachers clarify their own thinking

about NOS, and made them realise that they did understand the concepts. So their views of NOS did not change but they became more aware of these views through the self-reflection and discussion that participating in this research project required. The feedback from the written surveys and interviews made NOS ideas explicit to the teachers, as evidence for their views was presented back to them using the themes listed in Table 2.1.

To build on this new-found awareness of what constituted NOS, several of the staff were invited to share their knowledge and personal experiences with all the science staff at department meetings. This immediate feedback and use of findings is a well-recognised part of Action Research (Cohen et al., 2011) and in this case helped to build a shared understanding of NOS and of the value of NOS. It also boosted the teachers' confidence in using NOS by valuing their personal stories and making the NOS themes explicit. The rationale here was that if teachers were clear about NOS concepts and both comfortable and confident about their own views on NOS, they would be more likely to incorporate NOS in their own teaching. Thus a group culture was created where staff understood and valued NOS. One consequence of this was that all staff were willing to support the tasks asked of them related to the research, including administering the TOSRA surveys, being observed teaching, and making time to have interviews regarding both of these activities.

#### **7.2.6 Research Question 3a: Has the Nature of Science, as an overarching strand, been genuinely incorporated into the day-to-day teaching of science?**

The data from the TOSRA survey and interviews indicated that NOS themes were being regularly incorporated into science lessons, with both teachers and students describing many activities that showed a NOS approach. Experimental work was obviously used extensively across the Year 9 cohort, with themes such as the empirical NOS, scientific method and critical testing, and argumentation, commonly experienced. However, these themes were generally presented implicitly by teachers, although some were making ideas such as the difference between observations and inferences explicit in the second year of the project.

The lesson observations and interviews supported the TOSRA data and provided more detail concerning how often, and to what degree, NOS themes were being incorporated into lessons. The lessons observed were delivered using a NOS approach, as required by the NZ curriculum (Ministry of Education, 2007a). So NOS was the overarching strand used to deliver the content, with most of the specific NOS objectives covered, as shown in Tables 6.1, 6.2 and 6.3. However, as discussed in Section 6.2, and shown in Appendix G, most of the NOS themes were covered implicitly, with teachers structuring their lessons around NOS principles and modelling NOS themes such as argumentation. The main reason for this implicit approach seemed to be the expectation from teachers that simply by doing experiments the students would pick up NOS ideas, a belief found previously in many studies (Lederman, 2007).

Although only twelve lessons were directly observed, it was clear that the teachers involved did value NOS enough to try and deliver the content using a NOS approach. Even though these lessons were a tiny sample of the lessons delivered to all fifteen Year 9 classes over the whole year, the TOSRA data suggested that this NOS approach was common to all classes, with varying degrees of success. Teachers were trying to include NOS in their lessons, but struggled to find good resources and to make NOS themes explicit. When support and guidance were provided in the form of written resources or discussions about NOS in lessons, teachers were more able to make NOS explicit and to adjust their usual activities and experiments to specifically include NOS concepts.

Thus it is reasonable to conclude that NOS has been genuinely incorporated into the day-to-day teaching of science, and that teachers' views about NOS have changed as a result of the implementation of the new curriculum. However, this implementation has been largely driven by the current research project, which required teachers to reflect on their understanding of NOS, and provided them with significant resources to deliver NOS in their classes.

### 7.3 Implications of the study and recommendations

Many reports from around the world (The Royal Society, 2014; Tytler et al, 2008), have recommended that NOS be included in school science programmes for a variety of reasons, including producing citizens better prepared for life in the 21<sup>st</sup> century, and to increase the number of students entering science-related careers. The result has been the inclusion of NOS in many curriculum and policy documents (ACARA, 2015; Ministry of Education 2007a; NGSS Lead States, 2013) which require teachers to deliver NOS in their classrooms. One of the aims often stated in these reports and curricula is to make science in schools more engaging for students, with the claim that including NOS in lessons will help achieve this goal.

The results from this research project appear to show that the inclusion of NOS themes does increase the engagement of students in Year 9 classes, the implication being that it would be fruitful to consider how this approach might be transferred to other situations. I believe that the first step to convincing staff to even consider incorporating NOS is to persuade them that there is value to both their students and themselves by using a NOS approach. If teachers can see that incorporating NOS will improve the engagement of students without lowering their performance in high-stakes testing, they are more likely to take the first steps and try some NOS activities with their classes. Some practical steps that helped facilitate the inclusion of NOS during this research project, and which may have broader applications, are noted in the following recommendations.

- First, it is vital to build a shared vision concerning science teaching and the place of NOS with all the science teachers in the school. Recommended ways of achieving this include:
- Have all staff complete a survey about their views on NOS, such as the VNOS-D (Lederman et al., 2002), with a subsequent interview with the science curriculum leader.
- Arrange for staff to share their own NOS experiences in science staff meetings.

- Visit local science research institutions or commercial enterprises based on science, to see NOS in action.
- Invite local scientists and those commercialising science to share their stories about the application of NOS with science teachers.
- Encourage science staff to read popular science books, science magazines and visit science websites, and to share these stories with each other and their students. A list of popular science books recommended to staff during this project is given in Appendix H, while McComas (2008) provided a list of books suitable to illustrate historical aspects of NOS.

Second, adjust the programme of work for the target Year group to allow for meaningful delivery of NOS:

- Reduce the content of topics to allow for more extended investigations and time for exploration and discussion of NOS-related themes.
- Introduce new topics, or re-write existing topic schemes with a contextual focus, ensuring the content is relevant to the students. For example, replace the traditional topic on Light with one such as Radiation and the Body, so that students see how light and radiation affect them personally.
- Introduce a School Science Fair, where all students are required to carry out an investigation in an area of their own choosing. Provide time in the year's programme to accommodate these projects.

Third, provide material for teachers to use to deliver NOS:

- Write specific activities or experiments that include detailed guidance for teachers on how to make NOS ideas explicit, such as specific questions to ask at key points in the lesson.
- Include NOS ideas into task criteria and assessment rubrics. For example, structure the task so that the students have to cooperate and collaborate to complete it, and their degree of cooperation influences their final grade.
- Ensure that NOS-related activities are clearly visible in schemes of work so that teachers plan ahead to include them in lessons and lesson sequences.

- Provide well equipped science laboratories with good technical support so that interesting and varied experiments are possible, and are able to produce meaningful results.
  
- Fourth, monitor and feedback to teachers the effects of all strategies used:
- Survey students to see if they are engaged and enjoying science. Ask students to identify any activities they particularly enjoyed, learned from, or conversely, caused them to disengage.
- Collect data on students' achievement at all levels, and trial new strategies in response to any deficiencies identified. Teachers must be convinced that teaching with a NOS approach does not reduce student performance.
- Collect data on student subject choices. Increased student numbers choosing senior sciences is a powerful motivator for science staff to use strategies that are deemed to influence these choices.

Finally, provide ongoing professional development for staff:

- Identify a member of staff to be a NOS leader who will trial and champion activities over a period of years, providing support and encouragement to others.
- Once activities have been modelled, require all staff to produce NOS-related materials, share them with other staff, and reflect on their impact in the classroom.
- Observe lessons with a view to improving NOS delivery and provide specific feedback to teachers regarding NOS in their lessons. Include NOS themes in teacher observation rubrics.

These recommendations should all be incorporated in a collaborative manner, for example, teachers working together to agree on the key content to be taught in each unit. The aim is to establish a culture where NOS is valued and staff are prepared to take the initial risk of incorporating NOS in their lessons. If they find out for themselves that students are more engaged, with both teacher and students enjoying the lessons, they will be more likely to continue including NOS.

The key to implementing these recommendations and thus implementing NOS in a school is to have a person with the knowledge and enthusiasm to drive the process. This requirement has been noted in New Zealand, with Alton-Lee (2012) placing educational leadership that focused on student outcomes as the most significant factor in producing systematic change. Similar conclusions and recommendations were made by Lederman and Lederman (2012), regarding the large-scale implementation of NOS in schools in the Chicago area. They found that when significant professional development was provided to teachers over a period of several years, major gains were made in the NOS understanding of students and teachers, along with improved achievement. Successful strategies identified by Lederman and Lederman, included many noted in the current research, such as creating a supportive environment where NOS teaching episodes can be observed and critiqued. If, as well as the gains reported in science content and NOS knowledge, teachers could see gains in students' engagement, they would be even more likely to continue making NOS explicit in their classes. Thus, the results of science education research need to be made available to practicing teachers to help convince them to adopt successful strategies.

This transfer of educational research from published findings to practice within schools has however, long been recognised as a problem (Eisner, 1984; Kantrowitz, 2014). One response in New Zealand has to been to include the teaching as inquiry model as part of the NZ Curriculum (Ministry of Education, 2007a). Teachers are required to conduct their own mini-research projects with students in their classes, and reflect on whether the strategies they have tried achieved the desired outcomes. One of the aims of this requirement was to stimulate teachers to use educational research to either frame suitable questions for their inquiry or to find strategies they might employ. Hancock (1997) argued that the model of teacher as researcher is a very effective one for effecting change in teacher practice, but noted that there are many barriers to implementation, including the limited time given to teachers to carry out their own research.

Therefore, my final recommendation is to give teachers the time and support needed to act as researchers and agents of change within their own schools. My experience from this research project has been that reading the international science education

research gave me the knowledge and confidence to share ideas about NOS and to advocate for their inclusion in science lessons. The time available to me through the Teacher Study Awards scheme (Teach NZ, n.d.) made the reading and field work possible, thus enabling the implementation of NOS across the whole Science Faculty.

#### **7.4 Limitations of the study**

As a case study in the constructivist-interpretive paradigm there are obvious limitations to the conclusions drawn from this research. The very nature of life in a school setting is complex with many competing influences, and as Guba and Lincoln (1989) suggested, the role of the researcher in this situation is to provide sufficient evidence to support the explanations and interpretations made. Some possible limitations to consider when reviewing the conclusions and recommendations include:

- There are many factors which influence the engagement of students (Mosher & McGowan, 1985), such as their relationships with the teacher and with each other. Some of these factors have been identified, the intent being to establish the effect of teaching with a NOS approach; however, the complexity of factors influencing engagement is acknowledged.
- The school, and therefore its teachers and students, was only selected because I happened to work there.
- The selection of teachers and lessons to observe may have been biased towards those who wanted to demonstrate their NOS teaching to their Head of Department. However, all teachers who were asked, were willing to participate, and as the lessons transcripts show, all needed considerable support to deliver NOS.
- My presence in the room during lesson observations may have caused changes in the normal behaviour of both students and teachers. Feedback and questioning of students and teachers indicated that my presence had a minimal effect.
- The basis for selecting students for interviews following the lesson observations was from their reactions noted to events in the lesson. It is possible that a more random selection of students may have produced a more

complete picture of student engagement or otherwise. The influence of these selections was however, mitigated by interviewing students with both high and low TOSRA scores.

- As I was the sole researcher as well as the Head of the Science Faculty, both teachers and students may have altered their behaviour and comments to fit what they perceived I wanted. The openness and honesty of responses would suggest that this was not the case, as would the data collected anonymously through the TOSRA surveys, where both positive and negative comments were freely expressed.

As Shulman (1986, p. 13) argued, case methods can be used “as a means for developing strategic understanding, for extending capacities towards professional judgement and decision making.” I believe that even given the limitations described, the conclusions do contribute to understanding of the relationship between NOS and engagement, and the recommendations could well be applicable in many other schools. The aim has been to present sufficient evidence to enable others to make their own judgements as to whether the conclusions apply in their specific situations.

### **Suggestions for further research**

A key feature of science and NOS is the drive to keep asking questions (Osborne et al., 2003a), with new discoveries always opening up new avenues of research. The same can be said in relation to the current research, which has certainly generated new questions and lines of inquiry. In order to persuade teachers to adopt a NOS approach, or any new initiative, teachers must see value in the process for themselves and their students (Harland & Kinder, 1997). This thesis argues that teachers’ value highly engaged students in their classes, and that teaching with a NOS approach will contribute to this engagement.

Two other effects were noted in this thesis which contribute to teacher’ perceptions of value, but were not claimed to be a direct result of introducing NOS, and these should be investigated further. The first was that student achievement in regular testing on the science content improved, a finding supported by Lederman and Lederman (2012). The second effect was that there was an increase in the number of

students opting for science subjects in the senior school. Longitudinal studies following students who have been taught with a NOS approach are needed to see if this does influence their subject choices. If both increased student achievement and retention in the sciences were linked to teaching and learning about NOS, this would add considerable weight to arguments for the inclusion of NOS in science lessons. Another area where much research is needed in the classroom concerns the finer detail of how to produce the maximum impact for both increasing NOS understanding and engagement. It would be very useful for practising teachers to have the answers to questions such as:

- Which strategies are most effective and why?
- Which NOS themes are most effective and why?
- Considering the age of students, when should certain strategies or NOS themes be introduced? And in what order?
- Similar questions have been posed before (Deng et al., 2011; Lederman, 2007), regarding improvements to NOS understanding, but these should also be investigated with student engagement in mind.

Finally, an obvious extension of the current research would be to apply the recommendations made to a variety of other schools such as, single sex, rural, or ones with students from different cultural backgrounds. It would be useful to see how significant some of the individual factors are, for example, comparing the effect of establishing a shared vision amongst the staff, with the quality of the resources or the professional development provided.

## **7.6 Final Comments**

I was fortunate to meet Sir Paul Callaghan while working at Syft Technologies during my Royal Society Teacher Fellowship. Sir Paul was a strong advocate for the role science needed to play in the New Zealand economy. He set out his arguments in the book, *Wool to Weta* (2009), and challenged those working in the sciences to lead the way by developing profitable businesses based on science and technology. The challenge was to achieve this without waiting for central government or some

other agency to make things happen, by scientists and business people forming partnerships and create the opportunities themselves.

I believe that a similar vision and drive is needed if NOS is to become embedded as normal teaching practice in secondary schools. Governments around the world have introduced science curricula which require the teaching of NOS, but as the history of curriculum implementation shows, this does not generally result in significant change to teaching methods in the classroom. Changing teacher practice to use a NOS approach is not an easy task, but there are many resources and supports available, often provided by government, but left to individuals to find and use. A good example in New Zealand is the Science Learning Hub (Science Learning Hub, n.d.), a vast online resource making local science and scientists accessible to teachers, if they have the will and skills to use the material.

In order to persuade science teachers that it is worth the effort to deliver NOS, I believe that they need to be convinced that their own working conditions and job satisfaction will improve by adopting a NOS approach. Most of the research around NOS has focussed on the benefits to the students and wider society, for example equipping out future citizens for life in the 21<sup>st</sup> century through improved problem solving and critical thinking skills (Tyytler et al., 2008). As a practicing teacher, I too wish the best for my students and want them to succeed academically and to prepare them for the future. However, the immediate imperative is to deliver lessons that are enjoyable and productive, so that both the students and teacher gain personal satisfaction from their shared experiences. The key to this is having students who are highly engaged in their learning. By using a NOS approach, teachers can create engaging lessons which explicitly incorporate those 21<sup>st</sup> century skills.

This research project set out to investigate the effectiveness of the Nature of Science strand in the NZ science curriculum in terms of engaging Year 9 students in a New Zealand high school science programme. My analysis supports the view that teaching with a NOS approach does improve the engagement of students, by stimulating their thinking and making science more useful and relevant. My hope is that this research can be used to encourage teachers to include and value NOS, as they come to see that science teaching and learning can indeed be fascinating and fun!

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## **Appendix A**

VNOS-D survey



## VIEWS OF NATURE OF SCIENCE

(VNOS-D +)

Name: \_\_\_\_\_

Date:    /    /

### ***Instructions***

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question if needed.
- Some questions have more than one part. Please make sure you write answers for each part.
- This is not a test and will not be graded. There are no “right” or “wrong” answers to the following questions. I am only interested in your ideas relating to the Nature of Science.
- There is no time limit for completing these questions, but I recommend that you spend no more than 50 minutes. To ensure that I fully understand the intent of your answers I may ask to interview you following this task.

Thank you very much for taking the time to answer these questions. I hope you use this opportunity to reflect on your views of Nature of Science and feel free to request a copy to include as evidence for your Registered Teacher Criteria.

David Paterson

1. What is science?

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2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)?

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3. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.

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4. (a) How do scientists know that dinosaurs really existed? Explain your answer.

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(b) How certain are scientists about the way dinosaurs looked? Explain your answer.

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(c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?

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(d) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer.

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5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

(a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?

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(b) Why or why not?

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6. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer.

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7. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?  
a. If **NO**, explain why.

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b. If **YES**, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

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8. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

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9. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example.

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10. Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide examples.

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## **Appendix B**

Test of Science Related Attitudes (TOSRA):

1. As given to the students
2. Showing the items belonging to each scale and the assignment of a positive (+) or negative (-) orientation.

Name (you will not be identified in any research publications):.....

Form class: .....

Date:.....

	Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
<b>Set 1</b>					
1. Money spent on science is well worth spending.	1	2	3	4	5
2. School should have more science lessons each week.	1	2	3	4	5
3. Scientists are less friendly than other people.	1	2	3	4	5
4. Working in a science laboratory would be an interesting way to make a living	1	2	3	4	5
5. Doing experiments is not as good as finding out information from teachers	1	2	3	4	5
6. I would prefer to do an experiment on a topic than to read about them in science magazines.	1	2	3	4	5
7. I find it boring to hear about new ideas.	1	2	3	4	5
8. This country is spending too much money on science.	1	2	3	4	5
9. I would enjoy it more if there were no science lessons.	1	2	3	4	5
10. I would enjoy having a job in a science laboratory during my school holidays.	1	2	3	4	5
<b>Set 2</b>					
1. Science is man's worst enemy.	1	2	3	4	5
2. It is better to be told scientific facts than to find them out from experiments.	1	2	3	4	5
3. Listening to talk about science on the radio would be boring.	1	2	3	4	5
4. Science can help to make the world a better place in the future.	1	2	3	4	5
5. Scientists can have a normal family life.	1	2	3	4	5
6. I would prefer to do experiments than to read about them.	1	2	3	4	5
7. In science experiments, I like to use new methods which I have not used before.	1	2	3	4	5
8. Science lessons bore me.	1	2	3	4	5
9. I would like to belong to a science club.	1	2	3	4	5
10. A career in science would be dull and boring.	1	2	3	4	5

<b>Set 3</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>
1. Public money spent on science in the last few years has been used wisely.	1	2	3	4	5
2. Scientists do not care about their working conditions.	1	2	3	4	5
3. I would rather agree with other people than do an experiment to find out for myself.	1	2	3	4	5
4. I enjoy reading about things which disagree with my previous ideas.	1	2	3	4	5
5. Money used on science projects is wasted.	1	2	3	4	5
6. Science is one of the most interesting school subjects.	1	2	3	4	5
7. I get bored when watching science programs on TV at home.	1	2	3	4	5
8. I would enjoy visiting a science museum at the weekend.	1	2	3	4	5
9. I would like to teach science when I leave school.	1	2	3	4	5
10. I am unwilling to change my ideas when evidence shows that the ideas are poor.	1	2	3	4	5
<b>Set 4</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>
1. Scientific discoveries are doing more harm than good.	1	2	3	4	5
2. Scientists usually go to their laboratories when they have a day off.	1	2	3	4	5
3. Science lessons are a waste of time	1	2	3	4	5
4. I dislike repeating experiments to check that I get the same results.	1	2	3	4	5
5. In science experiments, I report unexpected results as well as expected ones.	1	2	3	4	5
6. Scientists are just as interested in art and music as other people are.	1	2	3	4	5
7. I would like to be given a science book or a piece of scientific equipment as a present.	1	2	3	4	5
8. I dislike reading newspaper articles about science.	1	2	3	4	5
9. I would prefer to do my own experiments than to find out information from a teacher.	1	2	3	4	5
10. A job as a scientist would be boring.	1	2	3	4	5

<b>Set 5</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>
1. The government should spend more money on scientific research.	1	2	3	4	5
2. Scientists are about as fit and healthy as other people.	1	2	3	4	5
3. A job as a scientist would be interesting	1	2	3	4	5
4. Few scientists are happily married.	1	2	3	4	5
5. I would rather find out about things by asking an expert than by doing an experiment.	1	2	3	4	5
6. I am curious about the world in which we live.	1	2	3	4	5
7. I dislike listening to other people's opinions.	1	2	3	4	5
8. I really enjoy going to science lessons.	1	2	3	4	5
9. I dislike reading books about science during my holidays.	1	2	3	4	5
10. I would dislike being a scientist after I leave school.	1	2	3	4	5
<b>Set 6</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>
1. Science lessons are fun.	1	2	3	4	5
2. Too many laboratories are being built at the expense of the rest of education.	1	2	3	4	5
3. Scientists do not have enough time to spend with their families.	1	2	3	4	5
4. When I leave school, I would like to work with people who make discoveries in science.	1	2	3	4	5
5. If you met a scientist, she/he would probably look like anyone else you might meet.	1	2	3	4	5
6. I would rather solve a problem by doing an experiment than be told the answer.	1	2	3	4	5
7. Finding out about new things is unimportant.	1	2	3	4	5
8. The material covered in science lessons is uninteresting.	1	2	3	4	5
9. I would like to do science experiments at home.	1	2	3	4	5
10. I would dislike becoming a scientist because it needs too much education.	1	2	3	4	5

<b>Set 7</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>
1. I would dislike a job in a science laboratory after I leave school.	1	2	3	4	5
2. Science helps to make life better.	1	2	3	4	5
3. I look forward to science lessons.	1	2	3	4	5
4. Scientists like sport as much as other people do.	1	2	3	4	5
5. I would prefer to find out why something happens by doing an experiment than by being told.	1	2	3	4	5
6. I like to listen to people whose opinions are different from mine.	1	2	3	4	5
7. I dislike science lessons.	1	2	3	4	5
8. It is better to ask the teacher the answer than to find out by doing experiments.	1	2	3	4	5
9. I would like to be a scientist when I leave school.	1	2	3	4	5
10. Talking to friends about science after school would be boring.	1	2	3	4	5

### **TEST OF SCIENCE-RELATED ATTITUDES**

TOSRA layout showing the items belonging to each scale and the assignment of a positive (+) or negative (-) orientation.

<b>1. Social implications of Science (S)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. Money spent on science is well worth spending.	1	2	3	4	5	+
2. Science is man's worst enemy.	1	2	3	4	5	-
3. Public money spent on science in the last few years has been used wisely.	1	2	3	4	5	+
4. Scientific discoveries are doing more harm than good.	1	2	3	4	5	-
5. The government should spend more money on scientific research.	1	2	3	4	5	+
6. Too many laboratories are being built at the expense of the rest of education.	1	2	3	4	5	-
7. Science helps to make life better.	1	2	3	4	5	+
8. This country is spending too much money on science.	1	2	3	4	5	-
9. Science can help to make the world a better place in the future.	1	2	3	4	5	+
10. Money used on science projects is wasted.	1	2	3	4	5	-
<b>2. Normality of Scientists (N)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. Scientists usually go to their laboratories when they have a day off.	1	2	3	4	5	-
2. Scientists are about as fit and healthy as other people.	1	2	3	4	5	+
3. Scientists do not have enough time to spend with their families.	1	2	3	4	5	-
4. Scientists like sport as much as other people do.	1	2	3	4	5	+
5. Scientists are less friendly than other people.	1	2	3	4	5	-
6. Scientists can have a normal family life.	1	2	3	4	5	+
7. Scientists do not care about their working conditions.	1	2	3	4	5	-
8. Scientists are just as interested in art and music as other people are.	1	2	3	4	5	+
9. Few scientists are happily married.	1	2	3	4	5	-
10. If you met a scientist, he would probably look like anyone else you might meet.	1	2	3	4	5	+

<b>3. Attitudes to Scientific Inquiry (I)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. I would prefer to find out why something happens by doing an experiment than by being told.	1	2	3	4	5	+
2. Doing experiments is not as good as finding out information from teachers.	1	2	3	4	5	-
3. I would prefer to do experiments than to read about them.	1	2	3	4	5	+
4. I would rather agree with other people than do an experiment to find out for myself.	1	2	3	4	5	-
5. I would prefer to do my own experiments than to find out information from a teacher.	1	2	3	4	5	+
6. I would rather find about things by asking an expert than by doing an experiment.	1	2	3	4	5	-
7. I would rather solve a problem by doing an experiment than be told the answer.	1	2	3	4	5	+
8. It is better to ask the teacher the answer than to find out by doing experiments.	1	2	3	4	5	-
9. I would prefer to do an experiment on a topic than to read about in science magazines.	1	2	3	4	5	+
10. It is better to be told scientific facts than to find them out from experiments.	1	2	3	4	5	-
<b>4. Adoption of Scientific Attitudes (A)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. I enjoy reading about things which disagree with my previous ideas.	1	2	3	4	5	+
2. I dislike repeating experiments to check that I get the same results.	1	2	3	4	5	-
3. I am curious about the world in which we live.	1	2	3	4	5	+
4. Finding out about new things is unimportant.	1	2	3	4	5	-
5. I like to listen to people whose opinions are different from mine.	1	2	3	4	5	+
6. I find it boring to hear about new ideas.	1	2	3	4	5	-
7. In science experiments, I like to use new methods which I have not used before.	1	2	3	4	5	+
8. I am unwilling to change my ideas when evidence shows that the ideas are poor.	1	2	3	4	5	-
9. In science experiments, I report unexpected results as well as expected ones.	1	2	3	4	5	+
10. I dislike listening to other people's opinions.	1	2	3	4	5	-

<b>5. Enjoyment of Science Lessons (E)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. Science lessons are fun.	1	2	3	4	5	+
2. I dislike science lessons.	1	2	3	4	5	-
3. School should have more science lessons each week.	1	2	3	4	5	+
4. Science lessons bore me.	1	2	3	4	5	-
5. Science is one of the most interesting school subjects.	1	2	3	4	5	+
6. Science lessons are a waste of time.	1	2	3	4	5	-
7. I really enjoy going to science lessons.	1	2	3	4	5	+
8. The material covered in science lessons is uninteresting.	1	2	3	4	5	-
9. I look forward to science lessons.	1	2	3	4	5	+
10. I would enjoy more if there were no science lessons.	1	2	3	4	5	-
<b>6. Leisure Interest in Science (L)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. I would like to belong to a science club.	1	2	3	4	5	+
2. I get bored when watching science programs on TV at home.	1	2	3	4	5	-
3. I would like to be given a science book or a piece of scientific equipment as a present.	1	2	3	4	5	+
4. I dislike reading books about science during my holidays.	1	2	3	4	5	-
5. I would like to do science experiments at home.	1	2	3	4	5	+
6. Talking to friends about science after school would be boring.	1	2	3	4	5	-
7. I would enjoy having a job in science laboratory during my school holidays.	1	2	3	4	5	+
8. Listening to talk about science on the radio would be boring.	1	2	3	4	5	-
9. I would enjoy visiting a science museum at the weekend.	1	2	3	4	5	+
10. I dislike reading newspaper articles about science.	1	2	3	4	5	-

<b>7. Career interest in Science (C)</b>	<b>Strongly Disagree</b>	<b>Disagree</b>	<b>Not Sure</b>	<b>Agree</b>	<b>Strongly Agree</b>	<b>Rating</b>
1. I would dislike being a scientist after I leave school.	1	2	3	4	5	-
2. When I leave school, I would like to work with people who make discoveries in science.	1	2	3	4	5	+
3. I would dislike a job in a science laboratory after I leave school.	1	2	3	4	5	-
4. Working in a science laboratory would be an interesting way to earn a living.	1	2	3	4	5	+
5. A career in science would be dull and boring.	1	2	3	4	5	-
6. I would like to teach science when I leave school.	1	2	3	4	5	+
7. A job as a scientist would be boring.	1	2	3	4	5	-
8. A job as a scientist would be interesting.	1	2	3	4	5	+
9. I would dislike becoming a scientist because it needs too much education.	1	2	3	4	5	-
10. I would like to be a scientist when I leave school.	1	2	3	4	5	+

## **Appendix C**

Classroom observation protocol

**Classroom Observation Record**

Date:

Period:

**Class:**                      Class type/description:

Number of students:

**Teacher:**

**Observer:**

**Description of classroom:**

**Lesson Objectives:**

**Timeline**

Start

10 min

20 min

30 min

40 min

50 min

60 min

**NOS elements**

**Comments**

## **Appendix D**

Interview protocols for teacher interviews

## Typical Interview protocol for Year 9 teachers concerning TOSRA results

Teacher: B1

Class: 9A

Date:

Thank you for taking the time to consider your class results from year 1.

Class: 9A	Social	Normality	Inquiry	Attitudes	Enjoyment	Leisure	Careers	Average
Start of year	37.4	39.5	39.9	38.1	36.7	29.5	33.0	36.3
End of year	40.6	44.1	42.3	39.2	37.6	29.8	34.7	38.3
Difference	+3.2	+4.6	+2.4	+1.1	+0.9	+0.3	+1.7	+2.0
Year 9 cohort end of year average	35.5	37.2	37.5	34.2	32.9	26.5	30.0	33.4

1. Relationship with class?
2. Relationships within the class ... any obvious misfits/bullying?
3. Comments on the overall view of TOSRA results ... do they seem valid?
4. Your class 9A went up particularly in the areas of: Normality of scientists  
Is there anything you did that might account for this?
5. Any comments from the class on the survey in Nov vs Feb?

Class: 9A

Student Name	Start of year TOSRA	End of year TOSRA	Difference	Comment
A1	37.7	44.1	6.4	Highest increase
A2	44.7	47.3	2.6	Highest score at start and end of year
A3	29.1	26.6	-2.5	Lowest scores and 2 <sup>nd</sup> largest decrease

6. Does the large increase in attitude from A1 reflect your view of him in class over the year?

7. Does the decrease in attitude from A3 reflect your view of her in class over the year?
8. Did you identify A2 as the most positive student in the class during the year?
9. Any individuals that surprise?
10. Did you do a Science Fair project with the class? If so how do you think it affected attitude of the class? Of individuals?
11. Any individuals that you particularly pushed or took an interest in?
12. Does it appear that academic success or otherwise correlates with attitude?

Extra questions asked at the end of the second year of the study:

1. How effective is the Nature of Science strand in the NZ science curriculum in terms of engaging Year 9 students in science lessons?
2. Have your views concerning NOS and/or its place in the curriculum changed as a result of being involved in this research project?

**Interview Protocol to follow-up responses to VNOS-D for Teacher C4**



**Research Project:** The effectiveness of introducing "The Nature of Science" strand into the New Zealand curriculum with regard to increasing student engagement in science.

**Time of interview:** ..... **Date:** .....

**Place:** .....

**Interviewer:** David Paterson

**Interviewee:** .....C4.....

**Notes for start of interview:**

Explain the purpose of the interview ... to follow-up completion of the VNOS-D+ form and ensure I understand the interviewee's responses, and so gain a genuine understanding of their position regarding NOS. Show previously signed research consent form.

Explain the interview process ... will consist of questions relating to their written responses on the VNOS-D form and will take no more than 50 minutes.

Describe the use of data ... will be both audio and written recordings. Both will remain confidential and at no stage will the interviewee's name be used in the thesis or any publications. Remind them that classroom observations may follow to help find out which NOS teaching strategies increase student engagement.

Ask if the interviewee has any questions at this stage.

**Sample Questions**

Tell me again about your background in science.

You obviously have a good understanding and firm views about science and science teaching. In which parts of your career do you think you gained the most insight into NOS ... school, undergraduate, commercial work, science training or teaching?

In response to Q1 or 2:

"You mention gathering evidence a few times. How much evidence is needed to support a theory or hypothesis?"

In response to Q1 or 2 if interviewee mentions proving or disproving an hypothesis or theory:

“Do you think scientists require a theory or hypothesis in order to begin experimenting?”

“How would you prove or disprove a theory?” Is either even possible?

In response to Q3 if interviewee mentions proving or disproving an hypothesis or theory:

“The history of science is full of examples of scientific theories that have been discarded or greatly changed. There is no reason to believe that the scientific theories we have today will not be changed in the future. Why do we bother to learn about these theories and teach them to our students?”

In response to Q4 on dinosaurs and scientists disagreeing with each other:

“It is very reasonable to say that data is scarce and that the available data could support several hypotheses equally well. However, scientists supporting the different hypotheses are very adamant about their own position and often publish very pointed papers in this regard. Why is that?”

Is it possible for scientists to always be objective when interpreting their findings? Is this a good or bad thing?

In response to Q6 on the structure of the earth:

“You mention that the model representing the inside of the earth is based on predictions which may not be 100% accurate. So are you comfortable using this model? What degree of certainty do you need in a model?”

In response to Q7 on creativity and imagination:

You mention creativity in planning experiments. Can you tell me more about the investigation you did in your previous job and how this required creativity?

“Creativity and imagination also have the connotation of creating something from the mind. Do you think creativity and imagination have something to do with science in that sense as well?”

In response to Q8 on theories and laws:

“In terms of status and significance as products of science, would you rank theories and laws? And if you chose to rank them, how would you rank them?”

Do you think theories can become laws or laws become theories? Why or why not?

In response to Q10 on science, society and culture:

You indicated that society and culture have impacts on science. Do you think the reverse happens ... that science or society influence culture/society?

“Some people believe that science is universal, independent from the culture it takes place in. How would you respond to these people?”

What PD have you done on NOS? Would you like to do some/more?

Have you read the NZ curriculum document which details NOS? If so, what did you think of it?

### **Notes for conclusion of interview**

Thank interviewee for their cooperation and assure them of the confidentiality of their responses.

Ask them if they would like to see the results of the questionnaire and interviews regarding their understanding of NOS.

### **Good interview practices**

From Lederman et al. (2002)

Use extended wait time

Avoid directive clues

Test initial views about an interviewee’s conceptions through probing questions

From Creswell (2008, p. 233)

Construct a detail interview protocol form, but be prepared to be flexible with questioning

Include an “ice-breaker” question to open the interview

Use probes to encourage participants to clarify or elaborate what they are saying, eg

“Could you explain your response further?” “What does .... mean?”

Make sure you listen more and talk less

Keep the interviewee focused and keep to time

Make sure the recording equipment works

## **References**

Creswell, J. W., (2008). *Educational Research: Planning, conducting and evaluating quantitative and qualitative research* (3<sup>rd</sup> ed.). Upper Saddle River, NJ: Pearson Education.

Lederman, N. G., Adb-El-Khalick, F., Bell, R. L., & Scharz, R, S. (2002). Views of nature of science questionnaire: towards meaningful assessment of learners’ conceptions of nature of science. *Journal of Research in Science Teaching* 39(6), 497–521.

### **Teacher Interview to follow-up lesson observation**

Teacher: B6                      Date of interview:

Lesson observed: Separation of mixture      Class: 9K      Date of observation:

Thank you for being part of this research project.

Was the lesson observation record/analysis an accurate account of the lesson? Was it useful for you as feedback? What are your general comments on how the lesson went?

Did you in the subsequent lesson go over the conclusion regarding why the separation worked in terms of particles? Do you think the activity helped the students understand the concept of dissolving?

Did you discuss in later lessons the various methods groups used and why/why not they worked or not?

Do you think that would have been interesting? Do you think they would have responded to that, if you had been able to do that?

Have you used that experiment before? Do you think it was worthwhile?

Did you consciously think of the NOS ideas that were given in the teacher notes when you structured the lesson?

Do you think the students picked up the NOS concepts implicit in this lesson? If so, what do you think they would have learned?

Do you think bringing out the NOS ideas more explicitly would improve the engagement of students?

Do you think there is value in writing NOS objectives and comments into lesson plans ... as we've put in here?

Did my presence in the classroom change your behaviour? Or the behaviour of the students?

Have you read the Science Learning Guide on TKI, or do you know that it exists?

Have you read the learning objectives in the New Zealand Curriculum related to NOS?

Any other comments?

Thank you

## **Appendix E**

Staff and student consent forms

*Research on the 'Nature of Science' ... how effective is NOS in  
engaging Year 9 students in science classes?*

**Information sheet for participating staff**

My name is David Paterson. I am currently completing a piece of research for my Degree of Doctor of Science Education at Curtin University, Western Australia.

**Purpose of research**

The purpose of this research is to determine whether teaching the Nature of Science strand of the NZ Science Curriculum improves student engagement in science classes. I am interested in finding out if learning about how science works, the thinking behind scientific ideas, and the connections between science and society, changes student attitudes towards school science. To do this I will ask you to complete a questionnaire about the Nature of Science which should take about 50 minutes. This will be followed by an interview (also about 50 minutes) to help me understand more fully the answers you give in the questionnaire. I will also be surveying the students and conducting some observations in lessons to see how the Nature of Science is being taught and to find out which teaching strategies are effective.

**Benefits of the research**

The research should benefit you personally by improving your own understanding of the Nature of Science. It should also provide you with strategies that actually make a difference in the classroom, as all findings will be shared. In a wider sense the research could help to inform teachers and science advisors of the benefits or otherwise of incorporating the Nature of Science strand in the NZ curriculum. This would then have planning and funding implications for the future.

### **Consent to participate**

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or responsibilities. You do not have to give any reason for your withdrawal. When you have signed the consent form I will assume that you have agreed to participate and allow me to use your data in this research.

### **Confidentiality**

The information you provide will be kept confidential and secure, accessible only by myself and my supervisor. Any interview transcript will not have your name or any other identifying information on it and in adherence to university policy, the interview tapes and transcribed information will be kept in a locked cupboard for at least five years, before a decision is made as to whether it should be destroyed. No individual student or staff member or identifying information will be used in any public presentation or published document. Pseudonyms will be used when presenting research findings.

### **Further information**

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval number SMEC-23-12). If you would like further information about the study, please feel free to contact me on 3329 129 or by email [ptd@cashmere.school.nz](mailto:ptd@cashmere.school.nz) . Alternatively, you can contact my supervisor at Curtin University, Dr. Rekha Koul [r.koul@curtin.edu.au](mailto:r.koul@curtin.edu.au), or the Curtin ethics officer (Ms Linda Teasdale) [l.teasdale@curtin.edu.au](mailto:l.teasdale@curtin.edu.au) .

**Thank you very much for your involvement in this research, your participation is greatly appreciated.**

*Research on the 'Nature of Science' ... how effective is NOS in  
engaging Year 9 students in science classes?*

**CONSENT FORM for Science staff**

- 
- 
- I understand the purpose and procedures of the study.
  - I have been provided with the participation information sheet.
  - I understand that the procedure itself may not benefit me.
  - I understand that my involvement is voluntary and I can withdraw at any time without problem.
  - I understand that no personal identifying information like my name and address will be used in any published materials.
  - I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
  - I have been given the opportunity to ask questions about this research.
  - I agree to participate in the study outlined to me.
- 
- 

Name: \_\_\_\_\_ (Please Print)

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

*Research on the 'Nature of Science' in science lessons*

**Information sheet for student participants**

My name is David Paterson. I am currently completing a piece of research for my Degree of Doctor of Science Education at Curtin University, Western Australia.

**Purpose of research**

The purpose of this research is to determine whether teaching the Nature of Science strand of the NZ Science Curriculum improves student engagement in science classes. I am interested in finding out if learning about how science works, the thinking behind scientific ideas, and the connections between science and society, changes your attitudes towards school science. To do this I will ask you to complete a questionnaire which should take no more than 50 minutes. Then I will conduct interviews lasting about 50 minutes with selected students to try and find out more about your attitudes towards science.

**Consent to participate**

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without having to give any reason for your withdrawal.

**Confidentiality**

The information you provide will be kept confidential. No individual student or staff member or identifying information will be used in any public presentation or published document. Pseudonyms will be used when presenting research findings.

**Further information**

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval number SMEC 23-12). If you would like further information about the study, please feel free to contact me on 3329 129 or by email [ptd@cashmere.school.nz](mailto:ptd@cashmere.school.nz) . Alternatively, you can contact my supervisor at Curtin University, Dr. Rekha Koul [r.koul@curtin.edu.au](mailto:r.koul@curtin.edu.au) , or the Curtin ethics officer (Ms Linda Teasdale) [l.teasdale@curtin.edu.au](mailto:l.teasdale@curtin.edu.au) .

**Thank you very much for your involvement in this research, your participation is greatly appreciated.**

*Research on the 'Nature of Science' in science lessons*

**CONSENT FORM**

---

- I understand the purpose and procedures of the study.
  - I have been provided with the participation information sheet.
  - I understand that the procedure itself may not benefit me.
  - I understand that my involvement is voluntary and I can withdraw at any time without problem.
  - I understand that no personal identifying information like my name and address will be used in any published materials.
  - I understand that all information will be securely stored for at least 5 years before a decision is made as to whether it should be destroyed.
  - I have been given the opportunity to ask questions about this research.
  - I agree to participate in the study outlined to me.
- 

Name: \_\_\_\_\_ (Please Print) Form Class \_\_\_\_\_

Signature: \_\_\_\_\_

Name of Parent: \_\_\_\_\_ (Please Print)

Signature of Parent: \_\_\_\_\_

Date: \_\_\_\_\_

## Appendix F

Student feedback form

### Student Evaluation of “Radiation & the Body” Unit

The level of work in this unit was: hard OK easy

I found this unit of study: very useful useful a waste of time

In this unit I learnt: a lot something nothing

This unit was: enjoyable OK not very interesting boring

The teacher seemed:

well informed and organised OK disorganised and /or unsure

The best activity was:

The worst activity was:

A comment I would like to make is:

## **Appendix G**

Strategies for teaching NOS noted during lesson observations.

## Strategies for teaching NOS noted during lesson observations in 2013

Teacher	NOS theme	Strategies	NOS emphasis by teacher
B7	Creativity	Newspaper on Space related issues. Creativity in marking criteria	Explicit in marking criteria, but not mentioned by teacher
	Argumentation	Students justify claims related to Space issues	Discussed the need for evidence in arguments
	Cooperation	Group work to complete research tasks. Cooperation in marking criteria	Strongly emphasised need for cooperation, but no link to NOS
B1	Social	Students shown video clip of the Hindenburg disaster	Implicit. No discussion directly linking to NOS
	Observation vs Inference	Students required to describe what happened during experiment	No NOS link or distinction made between observation and inference
	Scientific method	Experiment carried out as a 'recipe'	No NOS links made
B2	Empirical	Questions related to a timeline of science events	Explicit but some confusion in delivery
	Tentative	Questions about theories that have changed	Implicit
	Scientific method	Teacher explained the way theories are constructed from observations	Explicit
	Argumentation	Explain why ancient people came up with theories now deemed incorrect	Modelled through questioning, no explicit link to NOS
	Observation vs inference	Observations about a range of elements. List of valid observations created	Explicit for observation. Confusion over inferences made

<b>Teacher</b>	<b>NOS theme</b>	<b>Strategies</b>	<b>NOS emphasis by teacher</b>
B3	Empirical	Questions answered by experiments and empirical observations.	Encouraged good observations, no explicit link to NOS.
	Argumentation	Questions about ideas and evidence in class discussions	Modelled by teacher through scaffolded questioning. No explicit link to NOS.
	Scientific method	Students asked to make hypotheses and test them	Several episodes in class where teacher modelled good practise and questioned students. No explicit link to NOS.
P1	Empirical	Good observations emphasised during experiment	Observations mentioned but not explicitly linked to NOS
	Scientific method and critical testing	Need for repeats in experiments. Students challenged to offer explanations	Lesson structured to model these processes. No explicit link to NOS.
	Observation vs inference	Only recorded inferences. Students divided on the use of observations to make certain inferences.	Problems noted but not linked to NOS
	Argumentation	Students encouraged to debate variations in results	Need for argument noted but not linked to NOS.

## Strategies for teaching NOS noted during lesson observations in 2014

Teacher	NOS theme	Strategy	NOS emphasis by teacher
B1	Empirical	Students asked to make good observations during an experiment.	Need for direct observations emphasised. No explicit link to NOS
	Observation vs inference	Observations made during an experiment used to determine whether a chemical change had occurred	Implicit link to NOS, but incorrect inference accepted by the teacher
	Scientific method and critical testing	Whole lesson structure modelled good practise with links between experiment and theory	Implicit, with one explicit reference to scientific method by the teacher
	Argumentation	Questioning, debate and argument evident in the class	Good modelling of scientific argument, but no explicit link to NOS.
B6	Argumentation	Students were questioned and asked to justify their ideas.	Good modelling of scientific argument, but no explicit link to NOS.
	Scientific method and critical testing	Open-ended task with outcomes open to external scrutiny.	Well modelled but no explicit link to NOS.
	Socially/culturally embedded	Application of the ideas experienced during the lesson to practical uses in society.	Implicit, no direct link to NOS
	Empirical	Success of the task based on observations	Implicit, no direct link to NOS
	Cooperation	Team work to complete the separation challenge	Strong encouragement from teacher to collaborate and share ideas, but no direct link to NOS.

<b>Teacher</b>	<b>NOS theme</b>	<b>Strategy</b>	<b>NOS emphasis by teacher</b>
P2	Empirical	Encouraged students to make observations with all senses.	Brief explicit link to good science.
	Scientific method and critical testing	Repeated use of observation, hypothesis, and explanation	Well modelled throughout lesson, but no explicit link to NOS.
C1	Cooperation	Students worked in groups to complete experiment	Explicit link to the way scientists work
	Tentative	Tentative NOS related to students' experiment	Explicit, but hesitant explanation
	Scientific method and critical testing	Hypotheses made. Differing results discussed.	Explicit but hesitant link to NOS
B5	Scientific method and critical testing	Problems related to experimental method identified	Explicitly related to problems that scientists encounter
	Argumentation	Discussion about method and validity of results	Modelled, but no explicit link to NOS
	Empirical	Careful measurements and observations required, with discussion concerning these	Explicit link to the importance of good observations in science.

## **Appendix H**

Recommended reading for teachers about NOS

Rather than reading history or philosophy of science texts, or numerous academic papers on the nature of science, I would encourage science teachers to read some of the excellent material available in the popular press.

The following is a list of sources that I have read or viewed, and recommend to give an appreciation of the nature of science in many contexts:

Anderson, A. (2009). *After the ice: life, death and politics in the new arctic*. London: Virgin Books.

A detailed but easy to understand look at the complex interactions between individuals, nation states, scientists and wildlife, all trying to come to terms with the huge environmental changes taking place in the Arctic. Will an atmospheric scientist or an oceanographer give the same reasons for the loss of ice?

Bronowski, J. (1973). *The ascent of man*. BBC

Superb arguments for the inter-relationships between science and society, and a wonderful account of the nature of science as it changes and develops throughout human history. A thought provoking set of programmes made for television presented by this biologist, mathematician and historian of science.

Brooks, M., (2009). *13 things that don't make sense: The most intriguing scientific mysteries of our time*. London: Profile Books.

Shows how difficult it is to 'prove' or 'discover' anything, and how results can be interpreted in many ways. Did they really discover life on Mars?

Bryson, B., (2003). *A short history of nearly everything*. UK: Black Swan.

An entertaining journey through the history of science. Full of colourful characters arguing about many significant discoveries, with great descriptions of the lengths scientists go to in order collect and defend their data.

Callaghan, P. (2009). *Wool to Weta: Transforming New Zealand's culture and economy*. Auckland: Auckland University Press.

Well thought out arguments for the role of science in New Zealand. Full of examples and key individuals demonstrating scientific and entrepreneurial skills.

Casey, S. (2010). *The wave: In pursuit of the rogues, freaks, and giants of the ocean*. New York: Anchor Books.

A book combining the passion for big wave surfing with in-depth science examining the world's oceans. Shows the links between science and society through shipping, commerce, and insurance, intertwined with the awe inspired by gigantic waves.

Davidson, K. (1999). *Carl Sagan: A life*. New York: John Wiley & Sons.

A very readable account of one of the most well-known recent scientists, illustrating the very personal, human way in which science works. Did planetary scientists really have a role in ending the cold war?

Dawkins, R. (2006). *The selfish gene: 30<sup>th</sup> anniversary edition*. Oxford: Oxford University Press.

A fascinating look at the way theories are formed and change based on evidence. The original ideas formulated in 1976 are examined in the light of new evidence. Brilliant explanations of animal behaviour from the point of view of the gene, which answer many of those 'why' questions raised when watching wildlife documentaries.

Diamond, J. (1997). *Guns, germs, and steel: The fates of human societies*. London: Random House.

A brilliant example of the application of scientific processes and reasoning across the full scope of human history. Why were only a few animals domesticated? And why was their location so important to the rise of civilizations? Many theories proposed, discussed and defended, backed up by evidence from many different domains.

Diamond, J. (2005). *Collapse: How societies choose to fail or succeed*. New York: Penguin Books.

A detailed analysis of the ecological and cultural factors that led to the failure of specific civilizations, done with the tools of science. Weaves personal stories into a wide range of contexts, from ancient Mayan agriculture, to Norse settlements in Greenland, to modern day Montana.

Doidge, N. (2010). *The brain that changed itself: Stories of personal triumph from the frontiers of brain science*. Victoria, Australia: Scribe Publications.

As described on the back cover: An astonishing new scientific discovery called neuroplasticity is overthrowing the centuries old notion that the adult brain is fixed and unchanging. Full of stories about individual scientists, their experiments and patients, and how their efforts to understand the brain challenged existing thinking.

Hansen, J. R. (2005). *First man: The life of Neil A. Armstrong*. New York: Simon & Schuster.

A comprehensive coverage of the life of this amazing engineering scientist. The personalities and politics behind one of the greatest human achievements in science, or any field, sending a man to the moon.

Hohn, D. (2011). *Moby duck: The true story of 28,800 bath toys lost at sea and of the beachcombers, oceanographers, environmentalists, and fools, including the author, who went in search of them*. New York: Viking.

A wonderful tale from an English teacher who fell in love with the story of the little yellow ducks that floated around the world. He had to learn a great deal of science along the way, met many fascinating people and uncovered a lot more than he bargained for. Great examples of how science and society are inextricably linked, and how good questions can lead to great adventures.

Hooper, M. (2008). *The ferocious summer: Adelie penguins and the warming of Antarctica*. Vancouver: Greystone Books.

A very personal account of the lives of scientists involved in collecting and interpreting data in Antarctica. The passion and commitment to their projects is incredible, especially when seen in such an extreme environment.

Lorenz, R., & Mitton, J. (2010). *Titan unveiled*. Princeton: Princeton University Press.

The inside story of the Cassini mission to Saturn and deployment of the Huygens probe to Titan from one of the scientists involved from the beginning. Many examples of creative theories developed based on limited observations which had to be defended or modified as new evidence was gathered. Plus personal accounts of the way scientists interact with each other and the media, and just how much it means when ten years of your life is invested in a project that depends on technology operating millions of kilometres away from earth.

Rothenberg, D. (2005). *Thousand-mile song: Whale music in a sea of sound*. New York: Basic Books.

A wonderful fusion of science and art as this accomplished clarinettist, takes his music directly to the whales. Along the way we meet many scientists and others passionate about these amazing creatures, and learn about the role of science in protecting and understanding both whales and the oceans in which they live.

Ryan, T., & McKeivitt, S. (2013). *Project sunshine: How science can use the sun to fuel and feed the world*. London: Icon Books Ltd.

A detailed argument for the use of solar power in the 21<sup>st</sup> century. All other sources of energy are discussed and considered using scientific arguments but recognising the social significance of the debate.

Shenk, D. (2010). *The genius in all of us: Why everything you've been told about genetics, talent, and IQ is wrong*. New York: Doubleday.

A refreshing book which synthesises the latest research from genetics and cognitive science to show that we are not fixed by our genes. There is tremendous potential in all of us, and there are strategies to release this.

Tetro, J. (2013). *The germ code: How to stop worrying and love the microbes*. Canada: Doubleday.

A fascinating account of the importance of microbes in our lives, full of scientific stories and insights from an expert in the field. Although the pathogens are well covered Tetro explains how much of our health depends on the 'good' microbes.

Willingham, D. T. (2009). *Why don't students like school? A cognitive scientist answers questions about how the mind works and what it means for the classroom*. San Francisco: Josey-Bass.

Great explanations about the way all of us think based on research on learning and memory. Then these insights are applied directly to teachers with practical, useful advice.

## **Appendix I**

Strategies for teaching NOS as noted in the literature reviewed in Chapter 2.

<b>Strategy for Teaching</b>	<b>Rationale for Strategy</b>
<b>NOS</b>	
Use authentic, context-rich tasks	Demonstrates the complex, socially embedded NOS. Especially effective if linked to either genuine contemporary or historical events that contribute to learning of science concepts.
Integration of NOS with inquiry in relevant context	Provides deeper meaning and opportunities for personal decisions in experimental design or direction. Imagination and creativity can be encouraged.
Publishing inquiry work beyond the classroom	Models real science as it requires students to justify their work and be open to critique.
Choose tasks relevant to the students	Illustrates social NOS and provides direct meaning for the student. Scientific knowledge becomes useful and fruitful.
Open-ended questions	Models authentic science. Genuine sense of discovery.
Reflection	Promotes metacognition and focuses students on the value of both the concept and task. Encourages questioning.
Scaffolding	Needed to support both inquiry steps and reflection about NOS concepts. Students need the skills to carry out each step and to think about how and why they are done.
Questioning	Guides inquiry by providing appropriate hints. Focus on justifying explanations through the use of evidence.
Stories from science	Builds empathy with scientists as people struggling with concepts. Some NOS aspects are better illustrated with hindsight, e.g. tentative NOS.

<b>Strategy for Teaching NOS</b>	<b>Rationale for Strategy</b>
Visiting scientists – in person or through video clips	Provides authenticity, first-hand knowledge of what a scientist does. Especially powerful if has local relevance or connection.
Break inquiry process into small steps	Building knowledge and skills at age and developmental appropriate stages creates competence.
Group work/collaboration	Models the way scientists actually work and increases participation.
Argumentation/discussion	Defence of own opinions supported by evidence. Models the way the science community works to critique research.
Make NOS explicit	For example with tentative NOS, this empowers students to question ‘facts’ and beliefs. Promotes deeper understanding over the provision of ‘right’ answers. Helps conceptual change.
Create a supportive classroom environment	Students’ ideas are respected but able to be challenged. Allows modelling of the social NOS where scientists work in communities which both support and critique their efforts.
Valid formative assessment	Models authentic science. Scientists constantly respond to feedback from their experiments and peers. Feedback also enhances student learning.
Valid summative assessment	Scientists are judged on the quality of their work through publishing papers. Students value credits and qualifications, and gain recognition for their efforts.

## **Appendix J**

Strategies for engaging students as noted in the literature reviewed in Chapter 3.

<b>Strategy for Engaging Students</b>	<b>Rationale for Strategy</b>
<p>Opportunities for participation, including activities that are hands-on, minds-on and fun.</p> <p>Classroom discourse – whole class and small group</p>	<p>Inherently interesting activities increase participation. This leads to improved academic results and increased self-esteem</p> <p>Increases participation and gives value to individuals. Teacher can involve all students through supportive questioning and discussion.</p>
<p>Relevant curriculum</p>	<p>Relates to society so provides meaning for the student. Gives a sense of purpose.</p> <p>Learning now will improve opportunities later.</p>
<p>Feedback</p>	<p>Promotes mastery learning and self-efficacy.</p> <p>Focus on the skills required to complete the task, become a competent learner and achieve personal goals.</p> <p>More authentic – people in the real world receive plenty of feedback.</p>
<p>Scaffolding – providing structures, hints and prompts</p>	<p>Enables students to build their own knowledge. Promotes competency and cognitive engagement.</p>
<p>Group work</p>	<p>Addresses the need for relatedness.</p> <p>Increases participation and discourse which may be harder in whole class situation.</p>
<p>Positive relationships, teacher-student and student-student. Teacher is warm and caring.</p>	<p>Promotes emotional engagement and hence willingness to participate</p>
<p>Autonomy, or control over learning by giving students choices in what they do or how their work is presented.</p>	<p>Boosts intrinsic motivation and emotional engagement. Students show higher levels of persistence.</p>
<p>Promote mastery learning by emphasising effort, deep learning and self-improvement</p>	<p>Students achieve competence through effort and perseverance.</p>

<b>Strategy for Engaging Students</b>	<b>Rationale for Strategy</b>
Problem solving – present lesson objectives as questions	Cognitively and emotionally satisfying to solve problems or find answers through your own efforts
Supportive classroom environment	Promotes mastery learning. “It’s OK to make mistakes as long as we learn from the experience.”
Authentic work	Students perceive tasks as valuable to them and therefore worthy of their effort. Promotes mastery learning and competence.
Open-ended tasks	Students can find their own meaning. Intrinsically motivating as contributes to feelings of autonomy.
Self-reflection	Promotes successful cognitive strategies for learning, leading to increased competence and feeling of self-efficacy
Challenging work	Students value the work and gain satisfaction from achieving success.
Story telling	People find stories naturally interesting and engaging. Familiar structure makes it easier to assimilate new information.
Presenting student work to audiences beyond school	Enhances emotional engagement as others value the work and students have increased sense of ownership.
Visiting speakers – in person or through video clips	Provide authenticity by creating connections to the community beyond the school.
Valid assessment	Provides extrinsic motivation for both <i>performance</i> and <i>learning</i> goal oriented students.
Track engagement	Teachers quickly identify a student’s lack of engagement and put in place strategies to counteract any change.

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<b>Strategy for Engaging Students</b>	<b>Rationale for Strategy</b>
Teacher models engagement through enthusiasm, organisation and personal stories that reflect on successes and failures.	Students see what engagement looks like for a significant adult. Helps build relationships.

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## Appendix K

Five key teaching strategies effective for improving both engagement and NOS understanding, based on the literature reviewed in Chapters 2 and 3.

Strategy	Engagement	NOS
Supportive learning environment – teacher cares for each student, sets clear boundaries and establishes fair and tolerant behaviour.	Once students feel safe and emotionally engaged they want to participate and feel able to take the risks needed for mastery learning.	Students’ ideas are respected but able to be challenged. Allows modelling of the social NOS where scientists work in communities which both support and critique their efforts.
Explicit reflection through verbal or written questioning	Promotes successful cognitive strategies for learning, leading to increased competence and feeling of self-efficacy	Making NOS concepts explicit, followed by metacognitive activities which focus on the value of both the NOS concepts and tasks.
Scaffolding – teacher hints, through questioning or written frameworks.	Enables students to build their own knowledge. Promotes competency and cognitive engagement.	Needed to support both inquiry steps and reflection about NOS concepts. Students need the skills to carry out each step and to think about how and why they are done.

<b>Strategy</b>	<b>Engagement</b>	<b>NOS</b>
Classroom discourse – whole class and small group	Increases participation and gives value to individuals. Teacher can involve all students through supportive questioning and discussion.	Defence of own opinions supported by evidence. Models the way the science community works to construct and critique research.
Opportunities for autonomy, or control over their own learning by giving students' choices in what they do or how their work is presented.	Boosts intrinsic motivation and emotional engagement. Students show higher levels of persistence.	Provides opportunities for personal decisions in experimental design or direction. Imagination and creativity can be encouraged.