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Nature of science in teacher education:
Rationale, realities, issues and strategies

Rena Heap

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy in Education, The University of Auckland, 2014
Abstract

Developing students’ understanding of the nature of science (NOS), as a key component of scientific literacy, is regarded as a central goal in science education. The strengthening of this focus on NOS in school curricula provides an imperative for increased emphasis on NOS in science teacher education programmes. Such programmes need to encompass the development of a robust understanding of this often unfamiliar and core strand of science and also the ability to translate this understanding into effective classroom teaching and learning. Developing science education courses that support thinking and teaching about NOS is not without its challenges given the short time frame of teacher education programmes in general, and the even shorter time frame of the science education component of such programmes.

The aim of this research was to critically analyse the effectiveness of various course components designed to develop participants’ views of NOS, and to identify and investigate the various factors that mediated the development of participants’ pedagogical content knowledge for NOS. The study employed design research methodology, drawing on critical research and used a case study approach for its capacity to focus on the dynamics within a setting. The research had five phases, each with a different focus and each with a different cohort of primary teacher education university students, both graduate and undergraduate.

Findings from this research have identified a number of factors which facilitate the development of robust understanding of NOS and pedagogical content knowledge for effective NOS teaching and learning. These include explicit teaching of NOS; the use of generic activities as analogies; both contextualised and decontextualised instruction; the use of authentic contexts to deepen understanding; provision of structured opportunities for repeated reflection; Web 2.0 technology to scaffold reflection and knowledge building for NOS; microteaching and peer teaching to develop PCK and self-efficacy for teaching NOS; and the centrality of a metacognitive and learning-as-conceptual change framework. Findings from this research will inform the design of teacher education science courses and the pedagogical practices of preservice and inservice teachers.
Dedication

To, Matthew, Oliver, Leilani, Noa, Tessa, Mareta, those who are yet a twinkle in the eye, and all your fellow schoolmates in the years ahead.

The important thing is not to stop questioning. Curiosity has its own reason for existing. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvellous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity. ~ Albert Einstein
Acknowledgements

*Ehara taku toa, he takitahi, he toa takitini.*

*My success is not the work of one, but the work of many.*

There are certainly many who have been part of this work. To my supervisors, Derek Hodson and Maxine Stephenson I would like to express my deepest gratitude and heart-felt appreciation. I thank you sincerely for sharing your intellectual genius, inimitable scholarship, wise counsel, patience and glorious sense of humour. I’ll miss the laughter of our meetings keenly. I will be spurred on constantly by your legacy of encouragement, and generosity of spirit, as I add commas with abandon, banish split infinitives and think in threes.

Thank you, also, to each of the cohorts of students who generously gave their consent to participate in this study. I have learned so much from you.

To my fellows in the New Zealand science community, to work colleagues, and to friends at home and abroad, thank you all for your thought-provoking suggestions, friendly guidance, and the interest that each of you has showed over the years. In addition, the tremendous support of the department leadership team, Judy Parr, Gillian Ward and Helen Hedges, could never go unacknowledged. Thanks to each of you for making this possible.

Let me also acknowledge the generosity of editors and publishers in allowing the inclusion in this thesis of articles I have published. Sincere thanks to Bev France for allowing the addition of a co-authored work.

Finally I must thank my family for their patience and support, in particular Graeme. Thank you for carrying the lion’s share of the chores and for choosing to walk alongside me all the way. I can never adequately thank you for your tireless contribution and the countless hours you have spent listening to me talk about my research. *Ehara taku toa, he takitahi, he toa takitini.*
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Chapter 1:  
Introduction and Overview

Developing students’ understanding of nature of science (NOS) is regarded as a central goal in science education (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick, Waters, & Le, 2008; Duschl, 1990; Hodson, 2008, 2009a; Millar & Osborne, 1998; Southerland, Smith, Sowell, & Kittleson, 2007). This is emphasised in current reform efforts in science education and in the science curricula of many nations, including New Zealand. The major argument that underlies the emphasis on helping students develop informed views is that a robust understanding of NOS is widely regarded as a key element of scientific literacy (American Association for the Advancement of Science, 1990, 1993; Hodson, 2008, 2009a; Matthews, 2000, 2012; National Research Council, 1996; Tytler, 2007). The importance given to NOS in official curriculum documents has become so evident that Dagher and BouJaoude (2005) have stated that “improving students’ and teachers’ understanding of NOS has shifted from a desirable goal to being a central one for achieving scientific literacy” (p. 378).

The strengthening of the focus on NOS in school curricula provides an imperative for increased emphasis on NOS in science teacher education programmes. Such programmes need to encompass the development of student teachers’ and practicing teachers’ robust understanding of NOS, and also their ability to translate this understanding into effective classroom teaching and learning. Research on translating intentions of curriculum developments that stress NOS into practice suggests teachers need both depth in their understanding of NOS and the necessary pedagogical content knowledge (PCK) about what to teach, when to teach, and how to teach it. However, the limited time available in initial teacher education programmes in general, and in science education courses in particular, presents a very real challenge to teacher educators – and provides the motivation for this research.

The core rationale for this thesis was to research ways in which teacher education programmes can more effectively equip student teachers and practicing teachers to teach science in a manner that fully reflects the emphasis on NOS in current science curriculum documents. Understanding NOS, how to teach in an interesting and effective way, and valuing it as an educational outcome are all crucial if teachers are to promote a deep and robust NOS understanding among their own students.

Rationale for the Research

The phrase ‘nature of science’ describes the integration of philosophy, history, sociology, and psychology of science to understand the core values and assumptions underpinning the development of scientific knowledge (Lederman & Zeidler 1987; McComas, Clough, & Almazroa, 1998). It refers to matters such as what science is, how it works, the epistemic and ontological stance with which
scientists approach investigations of the natural world, the values and beliefs inherent in the development of scientific knowledge, the language used concerning NOS, and the complex relationship between science and society (Clough, 2006; Lederman & Zeidler, 1987; Matthews, 1994; McComas et al., 1998).

The range in the level of sophistication at which NOS can be explored is broad and a critical reading of the literature reveals no standard definition of a precise meaning of NOS. For this reason, in this thesis ‘NOS’ is used intentionally rather than ‘the NOS’ to avoid implying a specificity of definition. From the outset of this thesis it should also be clarified that my own view of NOS is broader than the views frequently reported in the literature – particularly in many of the studies which define and describe NOS as 5–7 tenets. Throughout the research, tenets were used in teaching, but as a starting place for discussion, rather than as something to be learnt, and most often phrased as questions (Clough, 2007), or used within a more complex view of ‘features of NOS’ (Matthews, 2012). They were useful in the research as an analytical framework.

Significant justifications for emphasising NOS in science teaching can be found in current science education research literature. The most obvious rationale is to address the wealth of simplistic views and/or misconceptions held by science teachers, their students, policymakers, and the general public (Clough, 2006; Driver, Leach, Millar, & Scott, 1996; Lederman, 1992; Rudolph, 2007; Ryder, Leach, & Driver, 1999). For example, that a set scientific method exists; that science ideas are unchanging; or that science is a collection of facts and not a process of knowledge seeking (Hodson, 1998; Nadeau & Desautels, 1994; McComas, 1998).

Failing to address NOS in science teaching will only perpetuate such misconceptions, regardless of intent, as teachers always communicate messages concerning NOS, whether or not they consciously choose to explicitly address NOS in their science teaching, since “[e]ver present in science content and science teaching are implicit and explicit messages regarding the NOS” (Clough, 2006, p. 464). Even teachers who themselves have a more robust NOS understanding may easily convey erroneous views through their instructional practices unless they vigilantly reflect on what they are communicating about NOS.

It is also argued that improving NOS teaching and learning will lead to deeper understanding of science concepts (Clough, 2004; DeBoer, 2000; Matthews, 1994; McComas et al., 1998; Songer & Linn, 1991). For example, in understanding the underlying ontological and epistemological assumptions of science, and the reasons for idealising the natural world, students will better understand science ideas that are clearly counter to everyday observation and common sense (Clough, 2006, 2009; Matthews, 1994). Through such NOS themes, students will more deeply understand scientific knowledge, and why it can change, since “Perceiving science as a process of improving our
understanding of the natural world turns the notion of tentativeness into a strength rather than a weakness” (McComas et al., 1998, p.12).

A further rationale for teaching NOS relates to the affective domain where an understanding of the social, creative, imaginative, and human nature of science may increase student interest in the sciences because they no longer see science as a ‘sterile’ endeavour (Clough, 2009). Logically such increased engagement in science would lead to a better understanding of science content.

Several important rationales exist for why students should possess a deep understanding of NOS that extends beyond the classroom, transcending from classroom into society. Included in these rationales are that NOS facilitates individuals and the collective public to:

- Demarcate between science and pseudoscience (Matthews, 1994), good science and bad science (Hodson, 2009a)
- Conceptualise the science and navigate technology they encounter in their lives (Driver et al., 1996; Ryan & Aikenhead, 1992)
- Understand how science plays a major role in contemporary culture (Driver et al., 1996)
- Understand and make decisions pertaining to socioscientific issues (McComas et al., 1998; Rudolph, 2007; Sadler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002)
- Discern the reliability, validity and trustworthiness of ‘scientific’ messages and arguments used by special interest groups, politicians, and corporations to promote particular economic, social, and personal interests (Hodson, 2011).

For example, in the case of global climate change, Rudolph (2007) states:

The situation with global warming is a telling case in point. Given that the majority of the public hold an oversimplified view of science – as an activity that is capable of producing verifiable knowledge by means of a carefully prescribed experimental method – it’s not surprising that those who seek to undermine public faith in the claims made by climatologists have highlighted the uncertainties in their work. This is a not-so-subtle way of implying that scientists have yet to hit the nail on the head with respect to global warming, with the upshot being that, since definitive evidence hasn’t been found to link human activity to global temperature increases, then we really don’t know for sure what’s going on, and, they argue with a wink, it clearly wouldn’t be prudent to take any rash actions at this point. (p. 2)

**NOS and Scientific Literacy**

Such arguments and rationale for developing students’ understanding of NOS coalesce around the need to prepare scientifically literate students (Wahbeh & Abd-El-Khalick, 2014). The term ‘scientific literacy’ was first coined by Hurd (1958) when he claimed that, “More than a casual acquaintance with scientific forces and phenomena is essential for effective citizenship today. Science instruction can no longer be regarded as an intellectual luxury for the select few” (p. 13). The social climate of the 1960s
and 1970s, with concerns of equity and access, saw educators push for science education that applied not only to individuals planning to enter a scientific field, but rather to all.

This was encapsulated in Roberts’ (1982) notion of curriculum emphases, which was later elaborated into the concept of ‘Vision I’ and ‘Vision II’ curricula (Roberts, 2007a). Vision I, according to Roberts (2007b), “looks inward at science itself – its products such as laws and theories, and its processes such as hypothesizing and experimenting” (p. 9) and is seen to be a good preparation for the future scientist. Vision II, in contrast, “looks outward at situations in which science has a role, such as decision-making about socioscientific issues” (p. 9) and offers an external view providing students sufficient insight to engage in critique about science and its implications. It has since become widely recognised in science education that the major purpose of science in the compulsory years of schooling should be the development of scientific literacy, rather than solely the preparation of students for further studies in science (Bybee, 1997; Fensham, 2000; Solomon, 1997). The key concern of advocates of scientific literacy is that the curriculum should prepare all students to engage with science in their adult lives (Symington & Tytler, 2004). Hodson (2003) and Roth and Barton (2004), among others, have taken this concept even further in arguing that scientific literacy is a collective as well as individual property, and an education for scientific literacy should prepare the individual to act in a sociopolitical context (Osborne, 2012).

Laugksch (2000) groups the common rationale for scientific literacy into two categories, which he labels ‘macro’ and ‘micro’. One macro-argument is that national economic wealth depends on competing successfully in international markets and that to compete, a nation must have a strong research and development base – which in turn requires a steady stream of scientists to keep the research and development base vigorous.

A second macro-level argument is that the public support of science is critical to the continued funding of scientific research (Shamos, 1995; Waterman, 1960). Furthermore, the more fully citizens understand how science works and what it can do for them, the more likely they are to support scientific and technological endeavour (Laugksch, 2000). Movements such as the Public Understanding of Science movement, and the Public Engagement with Science and Technology model, which encourage public discussion of issues such as climate change, genetically modified foods and nanotechnology, reason that increased public engagement with scientists and policy makers and increased transparency of decision making will lead to greater public confidence in the final decisions made on controversial issues (Dillon, 2009). One final macro-level argument is that increasing the public’s scientific literacy might help to dispel the perceived stereotypical image of science and scientists.

While the macro-level arguments support collective economic well-being, democracy and societal
cohesion, micro-level arguments focus on the benefits of scientific literacy to the individual. Such benefits could include, for example, increased job opportunities, wiser health decisions, and increased personal confidence about science and technology issues. The Organization for Economic Cooperation and Development (OECD)’s Programme for International Student Achievement (PISA) proposes that a scientifically literate person is “able to combine science knowledge with the ability to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity” (OECD, 1998, p. 5) and has “a willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen ... having opinions and participating in ... current and future science-based issues” (OECD, 2006, p. 24).

Hodson (2011) proposes that the overarching goal of science education is the attainment of critical scientific literacy, a science education that can equip students with the capacity and commitment to take appropriate, responsible, and effective action on matters of social, economic, environmental, and moral-ethical concern. Here, critical scientific literacy is the driving force for sociopolitical action:

> One of the major rationales for promoting critical scientific literacy, and for learning about science, scientists, scientific inquiry and scientific argumentation, is the need to furnish students with the knowledge, skills and attitudes to address socioscientific and environmental issues in a critical way and to reach informed decisions on a range of science-related and technology-related issues that impact them, their immediate family and friends, the surrounding local, national and global community, and the planet as a whole. In other words, scientific literacy plays a key role in building informed and responsible citizenship and contributing to environmentally responsible behaviour. (Hodson, 2011, pp. ix–x)

It can be seen that the arguments for NOS become the arguments for critical scientific literacy, which in turn become the arguments for science education itself. Symington and Tytler (2004), writing from an Australian perspective, consider school science education to have five key purposes:

- **The cultural purpose**: to ensure that all members of society develop an understanding of the scope of science and its applications within contemporary culture.

- **The democratic purpose**: to ensure that students develop sufficient scientific knowledge and sufficient confidence in science to be involved in debate and decision-making about scientific and technological issues.

- **The economic purpose**: to ensure a regular supply of people with strong backgrounds in science and technology in business and public life, and in science-related and technology-related careers, to secure the country’s future prosperity.

- **The personal development purpose**: to ensure that all members of society benefit from the contribution that the values and skills of science can make to their ability to learn and operate successfully throughout life.
The utilitarian purpose: to ensure that all members of society have sufficient knowledge of science to operate effectively and critically in activities where science can make a contribution to their personal well-being and quality of life. (See p. 1411.)

The rationale for scientific literacy as being beneficial to science, individuals and society is clearly correlated with the vision, values, and key competencies as mandated in the New Zealand curriculum document. This correlation provides additional rationale for the teaching of NOS and for the current research. For example, the vision of the New Zealand Ministry of Education curriculum is for young people who will “be confident, connected, actively involved, and lifelong learners” (Ministry of Education, 2007a, p. 8). The curriculum identifies five key competencies: thinking; using language, symbols, and texts; managing self; relating to others; participating and contributing. This vision and these competencies can be developed within a curriculum with a focus on scientific literacy, including NOS. Since the curriculum is compulsory for students up to the end of Year 10 (around 15–16 years of age), this provides external motivation for the teaching of NOS and justification for this research.

Regarding benefits to science and to society in New Zealand specifically, the late Sir Paul Callaghan, a physicist, Fellow of the Royal Society, and New Zealander of the Year in 2011, was passionate about the knowledge economy and the role of science in New Zealand and in securing sustainable economic growth for New Zealand. In his final keynote address at Strategy New Zealand, Mapping our Future (2011), he reiterated the absolutely critical role of science in sustaining New Zealand’s economy, and cited the New Zealand Company Fisher and Paykel’s domination of the world market in respiratory dehumidifiers and sleep apnoea devices as an example. He reasoned that we currently have 10 such companies but only need 100 such companies with 100 inspired entrepreneurs to secure New Zealand’s economy. Of course, this will not happen if we do not keep our young people interested in science and scientifically literate.

The democratic argument for scientific literacy is also particularly relevant in multicultural New Zealand and with respect to the Treaty of Waitangi as the founding document of our country, acknowledged in the curriculum document. The democratic argument maintains that democracy is upheld when all citizens are able to ask fundamental questions, analyse and challenge accepted norms, make judgments, use critical thinking and solve problems, and remain interested in scientifically related issues. Conversely, if sections of the general citizenry remain scientifically illiterate, uninformed, and/or disinterested, the privileged with access to the requisite knowledge stay privileged, and the scientifically illiterate remain powerless and marginalised (Keske, 2002). Pleis, Lucas, and Ward’s (2009) disturbing statistics show issues of equity within the differential statistical results that are seen across categories of race, gender, and socioeconomic status in the United States. These are equally apparent in New Zealand. For example, in New Zealand the incidence of diabetes is higher in non-European populations than in New Zealanders of European descent. Thus, Māori males are 3.5

7
times more likely to develop diabetes than European males, and are 6.5 times more likely to die of diabetes.

**Teachers’ Knowledge of NOS**

It has long been established that teachers’ NOS conceptions are an important factor in influencing students’ ideas about NOS (e.g., Merill & Butts, 1969). Regrettably, studies have consistently shown that science teachers hold naïve conceptions of NOS, which are indeed often similar to those of their students (e.g., Abd-El-Khalick, et al., 1998; Billeh & Hasan, 1975; Carey & Stauss, 1968; Dogan & Abd-El-Khalick, 2008; King, 1991). This pattern holds also in New Zealand (Compton, 2005; Heap, 2007; Hipkins, Barker, & Bolstad, 2005). Furthermore, teachers have not typically experienced in their own schooling the learning environments they are expected to create for their students (Schwartz, Northcutt, GunkutMesci, & Stapleton, 2013).

Much has also been written about attempts by science teacher educators to facilitate and account for the translation of a NOS understanding into teaching practice (Abd-El-Khalick & Lederman, 2000a; Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1999, 2007; Shwartz & Lederman, 2002). Initially, studies focused on teachers’ NOS understanding as a primary factor that influences whether or not they explicitly teach NOS to their students (Abd-El-Khalick & Lederman, 2000a). However, researchers have noted that holding ‘more sophisticated’ views of NOS does not necessarily translate into actual classroom teaching. Rather, a teacher’s understanding of NOS is a necessary but insufficient condition for effective and engaging NOS instruction (Abd-El-Khalick & Lederman, 2000a; Clough, 2006; Lederman, 2007). To teach NOS effectualy, teachers need a robust NOS understanding, but beyond that they also need to be able to “understand and notice [NOS] issues entangled in science content and its development, and then effectively incorporate [those] with content instruction” (Clough, 2006, pp. 487–488). It is NOS *pedagogical* content knowledge (PCK), rather than NOS content knowledge, that has been cited as a factor that may determine NOS teaching effectiveness (Clough, 2006; Lederman, 2007; Shulman 1986, 1987). Effective NOS PCK is characterised by the integration of appropriate pedagogical practices with strategically placed effective NOS instruction – that is, the teacher would know when, how and why to teach particular aspects of NOS so they are more accessible to students. In addition, the teacher’s decision making while teaching NOS would reflect their knowledge concerning how students learn and the goals they have for their students (Clough, Berg, & Olson, 2009).

John Dewey eloquently claimed, “the final reality of educational science is not found in books, nor in experimental laboratories, nor in the classrooms where it is taught, but in the minds of those directing educational activities” (Dewey, 1929, p. 32). So the views of NOS that reside in the mind of the teacher, and the goals the teacher holds for science education, direct the educational activities and will
determine the final reality of their students’ classroom experience of science. This provides a strong rationale to research effective approaches to developing NOS for teachers.

**Research Aim**

The aim of this study is to explore the influence of a science content course incorporating explicit NOS instruction on preservice primary teachers’ views of NOS, and their PCK for NOS. The central research questions guiding the inquiry are:

- What is the initial NOS understanding of a cohort of practising teachers?
- What is the initial NOS understanding of a cohort of preservice teachers?
- What strategies can be used to challenge existing misconceptions and/or develop robust NOS understandings?
- What strategies can be used to challenge and develop PCK for NOS in preservice teacher education?

Specifically, this study critically analyses the effectiveness of various course components designed to develop participants’ views of NOS and identifies and investigates the various factors that mediated the development of participants’ NOS views and their PCK for NOS. Information obtained from these analyses will add to the emerging body of research conducted in the area of NOS teaching and learning, and will inform the design of future research studies.

Significant research has emerged over recent years in two NOS-related areas; scientific argumentation and modelling as components of critical scientific literacy. For example, research studies have indicated that a robust understanding of argumentation, with dispute as one of the key drivers of science, is required for students to understand the kinds of knowledge claims that can be made and to be able to engage meaningfully in debate on socioscientific issues. Similarly scientific literacy requires an understanding of the roles of models and modelling including as explanatory systems and cognitive tools (Hodson, 2009). Both argumentation and modelling represent considerable and important fields of research but are beyond the scope of this research study.

From a wider educational perspective, this study will inform the pedagogical practices of preservice and inservice science teachers wishing to develop their students’ views of NOS. As an informed understanding of NOS is a crucial requirement for developing scientifically literate students, it is

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1 For example, Berland & Hammer (2012); Berland & Lee (2012); Duschl & Osborne (2002); Erduran (2008); Erduran, Simon, & Osborne (2004); Khishfe (2012); Newton, Driver, & Osborne (1999); Nielsen (2013); Ryu & Sandoval (2012).
2 For example, Bamberger & Davis (2013); Coll (2006); Coll, France & Taylor (2005); Gilbert (2004); Gilbert & Boulter (1998, 2000); Justi & Gilbert (2002); Lehrer & Schauble (2005); Nelson & Davis (2012); Taylor, Barker, & Jones (2003); Treagust, Chittleborough, & Miamala (2002).
imperative to provide science teachers with pedagogical tools and strategies to help achieve this goal. This study will add substantially to the understanding of how to meet this goal. It almost goes without saying that the rationale for this research is informed by its New Zealand context.

**NOS in the New Zealand Context**

Schooling in New Zealand is compulsory from ages 6 to 16. Primary schooling usually begins at age 5 in Year 1 and continues through to Year 8. Year 7 and 8 students attend either a primary school for Years 1 to 8 or an intermediate school for Years 7 and 8. The New Zealand Curriculum was revised in 2007, and was mandated as compulsory for all English-medium schools in 2010. A parallel document, *Te Marautanga o Aotearoa*, serves the same function for Māori-medium schools (Ministry of Education, 2008).

The curriculum specifies eight compulsory learning areas: English, the arts, health and physical education, learning languages, mathematics and statistics, science, social sciences, and technology. In addition, it specifies the values and key competencies considered essential for our young people to be “confident, connected, actively involved, and lifelong learners” (Ministry of Education, 2007a, p. 8). One of the stated purposes of science in the curriculum is that “students explore how both the natural physical world and science itself work so that they can participate as critical, informed, and responsible citizens in a society in which science plays a significant role” (Ministry of Education, 2007a, p. 17).

Science in the *New Zealand Curriculum* (Ministry of Education, 2007a) comprises four science contextual strands: Living World, Material World, Physical World, and Planet Earth and Beyond, these being four sub-disciplines of science. These contextual strands outline broad conceptual understandings and provide “contexts for learning” (p. 29) for Years 1 to 10. The fifth strand, the Nature of Science strand, is required learning for all students to Year 10, and is described as the “overarching unifying strand” (p. 28). The Nature of Science strand has four sub-strands: Investigating in Science, Understanding about Science, Communicating in Science, and Participating and Contributing.

New Zealand primary teachers are commonly generalist teachers responsible for implementing all eight learning areas of the curriculum. Few have a science background (Bull, Gilbert, Barwick, Hipkins, & Barker, 2010). There is growing evidence that teacher beliefs and commitments are the greatest controllable influence on student achievement (Hattie, 2012) and that teacher preparation is a powerful predictor of students’ achievement, perhaps even overcoming socioeconomic and language background factors (Darling-Hammond, 2000). However, international comparisons show that New Zealand primary teachers have fewer hours of preservice science education and less ongoing science professional development than international norms (Education Review Office [ERO], 2010; International Association for the Evaluation of Educational Achievement [IEA], 2011). Hence the
imperative to research effective strategies for developing NOS understanding within the short time frame available, as a rationale for the research.

Evidence from recent meta-analyses of research conducted in the United States shows that teacher professional development in science has a significant positive effect on student achievement (Blank & de las Alas, 2009) and that the amount of professional development (more than 14 hours) was an important factor (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). The TIMSS 2011 International Results in Science show that for New Zealand students in Year 5, the teachers of only 16% of New Zealand Year 5 students had, in the two years prior, undergone professional development in science content, 14% in science pedagogy or instruction and 16% in science curriculum, compared with the international averages of 35%, 34% and 35%, respectively (IEA, 2011).

It has been demonstrated that there is considerable variability in the amount and type of science learning experiences that New Zealand primary schools offer (ERO, 2004, 2010). The 2010 ERO report indicated that most primary schools face challenges in developing high quality science education programmes, with only 3% evaluated as having highly effective science programmes and 24% as having generally effective programmes. Sixty percent of primary schools had only partially effective programmes and 13% had non-effective programmes. In schools with effective programmes, the NOS strand received regular focus. Conversely, schools with ineffective or only partially effective programmes demonstrated little evidence of awareness of the NOS strand or its place in the curriculum. Evaluations all noted the need for a greater focus on teaching the NOS strand. One of the key recommendations from the report was that the New Zealand Teachers’ Council investigate the extent to which preservice preparation for teaching science in Years 1 to 8 is enabling teachers to build their confidence to teach science effectively. This provides a further rationale for the research.

Key findings from the most recent Trends in International Mathematics and Science Study (TIMSS), 2010/2011, which measures the mathematics and science achievements of samples of Year 5 and Year 9 students from 63 countries, showed that in the international context, instructional hours in science in New Zealand middle primary classrooms was low in comparison with nearly all other countries (in fact, all but 5 of 63 countries); the range of achievement was wider than nearly all the high performing countries and nearly all the countries who tested in English; there was a relatively high proportion of very low achievers and there were advanced achievers and very low achievers in all ethnic groupings. However, there were proportionately more Pākehā/European and Asian advanced achievers compared with the Pasifika and Māori ethnic groupings. Conversely, there were more very low achievers among Pasifika and Māori groupings than among Pākehā/European and Asian groupings. Regardless of the measure used to assess socioeconomic status (SES), students with lower SES had lower achievement than students with higher SES. New Zealand had one of the largest differences in achievement between these two groups (Caygill, Kirkham, & Marshall, 2013). Given the democratic and equity arguments
for NOS instruction, this disparity provides further rationale for the research. How can the needs of all students be met most effectively?

The TIMSS study also found that fewer New Zealand middle primary teachers felt well prepared to teach topics in science compared with their peers in other countries and fewer expressed high levels of confidence in their ability to teach science. These findings echo the previous TIMSS report in 2006, where at Year 5 the teachers reported spending significantly less time on science than in 2002. Student achievement, which had been increasing steadily until 2002, had by 2006 returned to 1994 levels. Pākehā/European and Asian student achievement was, on average, significantly higher than that of Māori and Pasifika students (Caygill, 2008).

Another international measure, The Programme for International Student Assessment (PISA) report, compares the performance of just over half a million 15-year-olds from 65 OECD countries. One of its mandates is to measure and compare how well countries are preparing their 15-year-old students to meet real life opportunities and challenges. The report, released in December 2013 (OECD, 2013) shows that while 15-year-olds who came through the New Zealand education system from 2001 to 2012 still scored above the OECD average in science, New Zealand’s ranking had dropped from 7th (in 2009) to 18th (in 2012) in science (May, Cowles, & Lamy, 2013). Some academic observers and statisticians, internationally, query the reliability of the PISA statistical methods (Stewart, 2013) but the PISA results should not be summarily dismissed. There is a test score gap between socioeconomically advantaged and disadvantaged students in every country, which shouldn’t be ignored.

PISA assesses three curriculum areas, each at three-yearly intervals: scientific literacy, reading literacy and mathematical literacy – with one area being the main focus and the other two the minor foci on a rotational basis. For 2009 and 2012, scientific literacy was a minor focus. Among the key findings from 2009 was that New Zealand students’ overall scientific literacy was higher than the OECD average, but when considering the proportion of New Zealand students achieving at the high levels of scientific literacy, the number not achieving even the lowest scientific proficiency levels was disproportionately large (Telford & May, 2010). Furthermore, the mean performance of Māori or Pasifika students in 2006, 2009, and 2012 was lower than the respective OECD mean (May et al., 2013).

Findings from New Zealand’s National Education Monitoring Project (NEMP) for science in 2007 add to this description of science education in New Zealand. In 2007, the final year in which this project operated, numbers of middle and senior primary students reporting that their class never did experiments with everyday things or with science equipment, increased significantly from those of 1999. Furthermore, those reporting they learned little about science nearly doubled (Crooks, Smith, &
Flockton, 2008). It was suggested that, because many primary schools were integrating science with other learning areas to teach a ‘topic’ in a multidisciplinary general inquiry approach, students may not have been recognising the science they were doing (Bull et al., 2010).

Consideration of the rationale for teaching NOS for scientific literacy, the requirements of the curriculum, findings, and recommendations concerning New Zealand students’ achievement in international tests, and national reports on science education in New Zealand, raises issues related to the nature of teacher knowledge of NOS and their effectiveness in teaching it. The increasing curricular focus on outcomes concerning NOS provokes us to reconsider the teaching and learning of NOS and to research effective strategies for NOS instruction in teacher education programmes. Unless and until teachers are both challenged and supported to change the ways they understand and enact science education in and for the 21st century, very little real change is likely to occur. How to structure preservice teacher education programmes to facilitate this change is a research priority.

**Methodology**

At the onset and over the duration of the research, scholarly subject and key indexing databases (including Web of Science, EBSCOhost, ProQuest, Scopus, Google Scholar, NZCER Journals Online, ERIC, Index New Zealand, and PsycINFO) were used with key terms and Boolean operators to identify relevant articles and texts in the field. Each work was reviewed in the context of its contribution to the understanding of the research aim and questions being studied in order to locate the research within the context of existing literature. In this critical evaluation, the provenance, authority, objectivity, persuasiveness, validity, reliability, and usefulness of each work were considered. The literature review provided a critical synthesis of these works in order to trace the progression of the field, identify the research gaps, examine controversies and differences of opinion, define and limit the problem for study and situate the research study within the larger field of historical and contemporary research on the nature of science and relate the findings of this research study to existing knowledge in the field both internationally and within the New Zealand context. This is presented in the thesis as Chapter 2, *Nature of Science: Still a Work in Progress*.

This theoretical background and context to the study being proposed was used to identify the research questions, develop a thesis position, and establish the rationale, relevance, and significance of the current study. Since the literature search was ongoing throughout the duration of the research, it was also used to shed light on earlier phases within the research.

This thesis employs an emerging methodology in education – design research. Design research involves “introducing innovations into real world practices (as opposed to constrained laboratory contexts) and examining the impact of those designs on the learning process” (Kelly, Lesh, & Baek, 2008, p. i). Designed prototype applications such as instructional methods, strategies, and software
programs and the research findings are then implemented back into the next phase of the design innovation in order to diffuse the innovation, impact practice positively, and build research evidence. Design research is open-ended and generative, producing innovations directed at challenges facing learners, teachers, and researchers. Innovations can include practices, products, procedures, and technologies that can foster educational improvement (Kelly, 2003). Design researchers are interventionist-observers, who draw on existing models of learning, and often also on the affordances of new technologies, to “perturb learning and teaching so as to document, measure, and theorize, about the way the participants in the learning environment respond” (Kelly et al., p. xiii).

Design-based research bears similarities to action research; for example, both identify real world problems and are accompanied by subsequent actions to improve the status quo. A key difference however, is that while action research involves successive iterations repeating in a cyclical manner, design based research builds upon rather than repeats an intervention (Reeves, Herrington, & Oliver 2005). Second, in design-based research, researchers usually take the initiative in the research process as both researchers and designers (Wang & Hannafin, 2005). In contrast, in action research it is usually the practitioners who initiate the research and then the researchers who help facilitate the research process. The axiological emphasis of design-based research is on utility. For example in the fourth phase of this research when ShareFlow was used as a Web 2.0 platform, the artefacts produced included: conceptual designs (e.g. use of Web 2.0 as a back channel to support reflection); improved methods (e.g. the use of directed questions to structure a back channel); models and systems (the physical layout of the Web 2.0 platform); and better theories (e.g. theories underpinning the particular and unique affordances of Web 2.0 for reflection and collective knowledge building).

Within this design research methodology, the research draws on critical research, best understood in the context of empowerment of individuals (Neuman, 2003). It adopts a position in which reality is constantly being shaped by social, political, and cultural factors and its purpose can be described as initiating change, in order to “help people change conditions and build a better world for themselves” (ibid., p. 81). It is considered appropriate for this research programme since underpinning both critical social science and the educational goal of scientific literacy is the emphasis they both place on transformation, emancipation, and change. The transformative, emancipatory role of scientific literacy is evidenced in that individuals who have a robust understanding of NOS can attain a level of scientific literacy that enables them to question, analyse and challenge accepted norms, make judgments, and solve problems in scientifically related issues – at a personal, community, and national level. Such individuals are therefore empowered to function within and change society. As noted earlier, those who are scientifically illiterate uninformed and/or disinterested, can remain powerless and marginalised in socioscientific issues – while the privileged with access to knowledge and engaging with the issues, stay privileged (Keske, 2002).
In the New Zealand context of this research, the achievement gaps between socioeconomically advantaged and disadvantaged students, such as the mean PISA performance of Māori or Pasifika students in 2006, 2009, and 2012, strongly support the need for change – a critical paradigm issue. Bishop (2011) draws on Ladson-Billings’ (2006) metaphor of fiscal deficits which accumulate to become an economic debt for the country, to argue that the accumulated achievement gap constitutes a debt (owed by society or the country) to Māori and underachievers in general. This is rationalised as the non-realisation of Article 3 of New Zealand’s Treaty of Waitangi that guarantees rights of citizenship to all citizens.

The key for Bishop (2011) is agentic teachers, those who can create engagement of all students through the creation of learning contexts that will allow students (including underachievers) to be part of the learning conversation. Such teachers would be supported by school systems of providing time and professional development, and government systems of priorities and funding. Agentic teachers in science education will be able to use their scientific literacy to help address the over-representation of particular ethnic and socio-economic groups of children and the marginalisation and diminished opportunities to learn for groups of children. This research seeks to prepare such teachers.

Critical theory also underpins the need to address the issue of those student teachers in each cohort who have themselves historically been silenced in class, related to their participation in science. Developing their own understanding of NOS and providing a more appropriate vehicle for communication such as the Web 2.0 tools used in the later phases of this research, could help address this. The anonymity of the Web 2.0 tools could give a voice to address their silence and provide a space to contribute to the conversation in the currency of ‘young people’. This research therefore was seen as having a potentially transformative function for the participants involved, for the students they will teach and for the lecturer.

A case study approach is used within the design research methodology for its capacity to focus on the dynamics within a single setting (Huberman & Miles, 2002) and provide rich description (Cohen, Manion & Morrison, 2011). Case studies may employ both qualitative and quantitative methods (Huberman & Miles, 2002); this study employs both in an iterative sequential mixed design. A case study requires in-depth data and the use of a range of methods for data collection where multiple sources of evidence can provide concurrent validity (Cohen, Manion, & Morrison, 2011). This mixed method approach enabled the researcher to capture crucial aspects of analysis which would have been lost, had only larger scale data collection methods such as surveys been used (Sarantakos, 2005).

The research also draws on conceptual change theory (Carey, 1999; diSessa, 2006; Strike & Posner, 1982, 1992). Conceptual change contrasts with learning such as skill acquisition and acquisition of facts, in that it posits that students must build new ideas in the context of old ones – therefore the
emphasis is on change rather than acquisition (diSessa, 2006). From a conceptual change learning perspective, it is recognised that all students (both in school and in teacher education) come to science sessions with pre-instructional conceptions and ideas about the phenomena and concepts to be learned that are not always in harmony with science views. Furthermore, these conceptions and ideas are firmly held and are often resistant to change. This applies to conceptions at the content level and also at meta-levels, namely conceptions of NOS and views of learning, and characteristics of the learners. Posner, Strike, Hewson and Gertzog (1982) argue that students, and scientists, change their conceptual systems only when several conditions are met; they become dissatisfied with their prior conceptions; the new conception is intelligible; the new conception is plausible; and the new conception appears fruitful for future pursuits, that is it should contribute to a progressing paradigm.

However, a purely learning as conceptual change approach is inadequate in that it does not address situations where, despite deliberate attention to students’ prior conceptions in constructivist approaches, some students still do not achieve the desired learning goals (Anderson, 2007). A more situated view of science learning is necessary in this research study. From a sociocultural perspective, there is also a need to address the importance of the emotions/affective domain of learning. A multiperspective position of conceptual change recognises the importance not only of the context in which teaching and learning happens, but also of the environment in which student interactions take place. Learning is always deeply shaped by the particular social and material characteristics of the learning environment (Wells & Claxton, 2008). Hence, the analysis of discourse in small-group inquiry, individual learning, or whole-class instruction is essential for discerning the quality of the learning outcomes (Duit, Treagust, & Widodo, 2008).

Sociocultural theories view learning not purely as what individuals do but rather as increasing participation in a community of practice that is socially, culturally, and historically located, through socially-mediated action (Lave & Wenger, 1991; Wenger, 1998; Wertsch, 1991). Here, knowledge does not just reside inside the head of an individual, but is distributed to various extents at different times across the members of the learning community (Bell, 2005a; Lave & Wenger, 1991; Rogoff, 2003). A community of practice is considered to be a group of people who engage in a process of collective learning in a shared domain of human endeavour. This reflects the fundamentally social nature of human learning. Learning involves socially mediated action (Bell, 2005b; Wertsch, 1991). Participatory knowledge construction represents learning less as knowledge acquisition by an individual, and more as participation in a social process of knowledge construction (Salomon & Perkins, 1998). This perspective informed each phase of the empirical research, and involved technology as a mediator of learning in two phases.
**Research design and participants**

The research has five phases, each with a different focus, and each with a different cohort of student teachers. The first cohort of students was inservice teachers who were enrolled in study part-time, while still teaching, to upgrade their teaching qualifications. Each of the other four cohorts were preservice teachers, with students in phase 2 and phase 4 enrolled in a three-year Bachelor of Education degree, and phases 3 and 5 being students with an existing degree enrolled in the one-year Graduate Diploma of Teaching (Primary Specialisation), a post-graduate teaching qualification.

Both Bachelor of Education and the Graduate Diploma of Teaching programmes have a compulsory science course of one semester duration. This is the only compulsory science course. The course content is similar across both of the programmes and covers at least one topic from each of the four contextual strands, with NOS as the underpinning strand. The classes are interactive and strongly feature practical work, group work, and discussions to address science content knowledge, pedagogy, and NOS. In the Bachelor of Education programme, there is also one optional science/technology course that can be taken in addition to the compulsory course. This course is designed to enable students to recognise the differences between the enterprises of science and technology in terms of their different purposes and different epistemologies (see Appendix A for indicative course prescriptions, learning outcomes and course overview).

The five phases of the research were consecutive, with the findings of each phase informing the next as an iterative sequential mixed design where the methodological-analytical-inferential loop is recurrent and conclusions emerging from the inferential stage of a study may lead to further data gathering and analysis. Both qualitative and quantitative approaches were used interdependently at all stages of the study and the design criteria accounted for triangulation, complementarity, initiation and expansion (Teddie & Tashakkori, 2009). Without multiple data sets, both qualitative and quantitative, it would not be possible to comprehensively answer the thesis research questions.

Essentially each of these research phases represents a case study. The total timespan for the data collection phase of the five phases was four years. Phases 1 to 4 are reported in Chapters 3 to 6, respectively, of the thesis. Phase 1 of the research (reported in Chapter 3) looks at structuring reflection in a course in order to develop NOS understanding. Phase 2 (reported in Chapter 4) examines the use of authentic contexts to deepen NOS conceptual understanding. Phase 3 (reported in Chapter 5) examines the use of Web 2.0 technology as a tool to provide repeated opportunities for reflection on NOS in order to effect conceptual change. Phase 4 (reported in Chapter 6) extends the examination of Web 2.0 further, and uses a different Web 2.0 tool. The final phase of the research, phase 5 (reported in Chapter 7) examines the use of microteaching and peer teaching to develop PCK and self-efficacy for NOS. Table 1.1 presents an overview of the research phases, showing the number of students involved, the programme of study, and the duration of the course in which the research phase took place.
Table 1.1 Research phases

<table>
<thead>
<tr>
<th>Research phase</th>
<th>Number of students</th>
<th>Programme of study</th>
<th>Programme duration (Years)</th>
<th>Level</th>
<th>Hours of instruction(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>Bachelor of Education (Primary or Early Childhood Specialisation)</td>
<td>1</td>
<td>Bachelor 1st year</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>46</td>
<td>Bachelor of Education (Primary Specialisation)</td>
<td>3</td>
<td>Bachelor 3rd year (Optional course)</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>Graduate Diploma of Teaching (Primary Specialisation)</td>
<td>1.25</td>
<td>Postgraduate 1st year</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>Bachelor of Education (Primary Specialisation)</td>
<td>3</td>
<td>Bachelor 1st year course, taken in 2nd year of programme</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>145</td>
<td>Graduate Diploma of Teaching (Primary Specialisation)</td>
<td>1.25</td>
<td>Postgraduate 1st year</td>
<td>24</td>
</tr>
</tbody>
</table>

\(^1\) Semester breaks, in-school placements, and programme structure mean that these hours of instruction are not in consecutive weeks. Each programme of study takes place within a single semester of approximately 5 months duration. For each hour of face-to-face instruction, students are expected to complete approximately two hours of additional study (including the completion of assignments).

The main impetus for the ongoing research has been a desire to improve the teaching of NOS by beginning teachers. To research ways to do so, a series of overarching research questions were developed to serve as a framework for each phase of the research. The intention was to use the outcomes of the research on each of these questions, with each cohort, to inform changes in practice within the courses for successive cohorts. To reiterate, the approach resides within a design-based research tradition that recognises the importance of context and the complexity of the variables that lie within the learning processes (Brown, 1992; Kelly et al., 2008).

Data Collection

A case study requires in-depth data and uses a range of methods for data collection (Cohen et al., 2011). The study employed mixed data collection methods within each of the five case studies/research phases. Multiple sources of evidence can provide concurrent validity, if there is high correlation of data from different instruments (Cohen et al., 2011). Table 1.2 gives the main data sources for each phase together with the timing of the use of the data tool within the course.

Regarding the choice of tool to probe the understanding of NOS held by the participants, different tools were used across the five phases of research. The data tools have the two-fold purpose of developing students’ thinking on NOS as well as being a means to gather data for analysis. The choice of tool was based on the course, the participants and the time available. In case studies 1 and 3, the Views of Science, Technology & Society (VOSTS) questionnaire was used. VOSTS was developed empirically by Aikenhead, Ryan and Fleming (1989), over a six-year period, using 10,800 Canadian
students. It is an inventory of multiple-choice items which addresses a broad range of topics related to the epistemology and sociology of science. Each item consists of a statement with several reasoned viewpoints or positions. Unlike other quantitative tools, a student-centred process was used to develop these viewpoints or positions for each item. By substituting positions derived from a theoretical viewpoint with positions derived from student response patterns the criticism of developer bias is addressed (to some extent), ambiguity is reduced and validity is improved (Aikenhead & Ryan, 1992).

The shift towards including more qualitative open-ended approaches in both psychometrics research design and in educational research has also been applied to the assessment of understandings of NOS (Lederman et al., 1998), particularly over the last two decades. One of the most frequently used qualitative tools for NOS assessment is the Views of Nature of Science (VNOS) Questionnaire. VNOS –C (Abd-El-Khalick & Lederman, 2000a) was used in the fourth case study of this research. The VOSTS questionnaire takes longer to complete than the VNOS-C questionnaire, but does expose the students to a wide range of views in the multiple-choice offerings for each question. The courses of study in case studies 1 and 2 were longer, and therefore the use of VOSTS was possible and justified as an instructional as well as an assessment tool. The shorter duration of the course in the fourth case study prompted the adoption of VNOS-C.

A third, also qualitative, questionnaire used in the first three case studies of this research, was an open-ended questionnaire which required the students to complete 4 stem statements about science. Only the open-ended questionnaire was used in case study 2, as the purpose of this phase was the identification of NOS and NOT in authentic contexts (for which specific assessment tools were designed). Similarly the data collection tools in case study 5 focussed on self-efficacy and translation into practice rather than an assessment of NOS understanding. Each of the methods of data collection and analysis is described and discussed in the following chapters.
Table 1.2 Data collection methods

<table>
<thead>
<tr>
<th>Case study</th>
<th>Data collection tool</th>
<th>Position in course</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open-ended questionnaire</td>
<td>Pre- and post-</td>
</tr>
<tr>
<td></td>
<td>Views of Science, Technology &amp; Society (VOSTS) questionnaire</td>
<td>Pre</td>
</tr>
<tr>
<td></td>
<td>Reflective journal writing</td>
<td>Throughout course</td>
</tr>
<tr>
<td>2</td>
<td>Open-ended questionnaire</td>
<td>Pre-</td>
</tr>
<tr>
<td></td>
<td>Set task to identify &amp; illustrate NOS (&amp; nature of technology)</td>
<td>Mid-course</td>
</tr>
<tr>
<td></td>
<td>Task to justify NOS (&amp; nature of technology)</td>
<td>Mid-course</td>
</tr>
<tr>
<td>3</td>
<td>Open-ended questionnaire</td>
<td>Pre- and post-</td>
</tr>
<tr>
<td></td>
<td>Views of Science, Technology &amp; Society (VOSTS) questionnaire</td>
<td>Pre</td>
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Ethical Issues

Approval for this study was given by the University of Auckland Human Ethics Committee (UAHPEC). There are particular ethical issues associated with conducting a research project so closely linked to the student teachers’ own courses, particularly with the researcher being a lecturer in the courses. Therefore, the research and lecturing practice has adhered strictly to the ethical guidelines of UAHPEC and the granted ethics application. In researching with my own students, the most significant ethical issue was the conflict of interest, or the appearance of conflicts of interest since, as I was both researcher and lecturer, a power relationship existed. To address this issue, several steps were taken. The students were assured, in each research phase, that participation was voluntary and that the lecturer would not know at the time or at any time in the future, who agreed to participate. Only the research assistant had access to the consent forms and to any identifiable data. Some of the data sources, such as evaluations or questionnaires, were anonymous, but even here students could place a cross on their work to indicate that they did not wish it to be used for the research. No material was made available for research purposes until after the student grades were finalised and locked down by
the administration. Therefore, participation or non-participation could not affect grades or student-lecturer relationships.

Many of the course artefacts used for the research were completed as part of the students’ standard course work. However, only the work of those who had agreed to participate was copied by the research assistant and this work was anonymised before being passed to the researcher (after the grades were locked down). All participants were provided with extensive information, via information sheets, on the purpose of the research, participant involvement and intended use of the results, so that their consent was fully informed. All participants were given the opportunity to have their questions answered. Participants were also informed of their right to withdraw, through the research assistant, any artefacts (other than anonymous data which could not be withdrawn) up until the start of data analysis. When using Web 2.0 technology platforms, students could use a self-selected pseudonym if they chose. Any reporting or publishing of findings, including this thesis, is done in a way that does not identify the individual student sources or the cohorts of students. So to protect the anonymity of the students, dates have not been given for each research phase. The data will be destroyed 6 years after date of ethical approval for the research

This study will be continued and the research developed further as additional students complete the programmes.

**Thesis Format**

Chapters 2–5 and Chapter 7 of this thesis have been submitted as individual papers to international academic journals, under the University of Auckland Revised 2011 PhD Statute and Guidelines. Chapter 6 is a published monograph chapter. Chapter 4 is an article co-authored with Associate Professor Bev France and is reprinted here with kind permission.

Given this format of articles for submission, there will be elements of repetition between the chapters, especially regarding the background contextualisation literature and the methodology.
Chapter 2:  
Nature of Science: Still a Work in Progress

Where From?

For more than 150 years, there has been advocacy for including the cultural, educational, personal and scientific benefits of infusing the history and philosophy of science into science education – that is, teaching about the nature of science (NOS) while teaching science (Matthews, 2012, p. 3). In a lecture to the Royal Institution of Great Britain in 1854, on the “Influence of the History of Science Upon Intellectual Education”, William Whewell, one of the leading figures of nineteenth-century science, co-founder and president of the British Association for the Advancement of Science, fellow of the Royal Society, scientist, philosopher, historian, theologian and polymath addressed the importance of the nature of science in education, saying, “the history of science … ought to … form a distinct and prominent part of the intellectual education of the youth of those nations” (Whewell, 1854, pp. 248–249).

The early twentieth century saw, among others, John Dewey in the United States and Fredrick Westaway in England reiterating this advocacy. Dewey (1916) presented the argument that understanding scientific method was more important than the acquisition of scientific knowledge since, “no one can carry around with them a museum of all the things whose properties will assist the conduct of thought” (p. 157). Similarly, Westaway’s rhetoric is as appropriate today as it was almost a hundred years ago:

Now that science enters so widely and so intimately into every department of life, especially in all questions relating to health and well-being, it is important that the community should have a general knowledge of its scope and aims. (Westaway, 1929, p. 9)

Through the mid-1900s, the importance of addressing the nature of science and science education became even more evident. In the United States, the National Society for the Study of Education (established 1901) explicitly emphasised that students should understand not only scientific knowledge but also the nature of the enterprise (Hurd, 1960), thus placing NOS on equal footing with understanding of science content: “There are two major aims of science teaching; one is knowledge, and the other is enterprise” (Hurd, 1960, p. 34). Similarly, Joseph Schwab (1962) advocated a shifting of emphasis in school science education away from the learning of scientific knowledge (the products of science) towards an understanding of the processes of scientific inquiry and the structure of scientific knowledge.
This shift in emphasis resulted in a series of curriculum initiatives such as the Nuffield Science Projects in the UK during the 1960s with its pedagogy of “discovery learning” underpinned by an inductivist model of science and a Bruner-inspired “inquiry method” (Matthews, 1989, p. 3). The less than anticipated outcomes of these initiatives led to the burgeoning of ‘process approaches’ to science education. These were exemplified in the UK by Warwick Process Science, and Active Science; in the United States by initiatives such as Science – A Process Approach; and in Australia by the Australian Science Education Project. These curriculum approaches arguably placed so much emphasis on process that it appeared as though the process itself subsumed the importance of science knowledge and was seen as almost ‘content-free’.

With the publication of Kuhn’s (1962) Structure of Scientific Revolutions, historians and philosophers of science began to integrate psychological and sociocultural elements into descriptions of the way science works, placing science within social and cultural contexts. The term ‘scientific literacy’ was enthusiastically taken up by many science educators as a useful slogan or rallying call (Hodson, 2011; Roberts, 1983, 2007a), with an understanding of NOS as a core component of this literacy. In 1987 the International History, Philosophy, and Science Teaching Group was established with its biennial conferences and the foundation, in 1992, of Science & Education – the first journal devoted primarily to NOS issues in education.

The 1980s saw the inclusion of the teaching of NOS in numerous US, UK, Canadian, Turkish, Greek, and other national and provincial government educational reports, reform documents and curricula (McComas & Olson, 1998). For example, concern with NOS is clearly seen in affirmations of the American Association for the Advancement of Science (AAAS), especially in its landmark 1989 publication Project 2061: Science for All Americans (AAAS, 1989a) and The Liberal Art of Science (AAAS, 1990). The latter stated that:

The teaching of science must explore the interplay between science and the intellectual and cultural traditions in which it is firmly embedded. Science has a history that can demonstrate the relationship between science and the wider world of ideas and can illuminate contemporary issues. (AAAS, 1990, p. xiv)

Similarly, in the UK the first National Curriculum for England and Wales (Department for Education and Science, 1989) included a strong focus on the history and philosophy of science. This trend was not maintained as early revisions to the National Curriculum saw the strand on the history and philosophy of science “hastily removed” from the curriculum as a result of teachers’ lack of understanding of the content (Gilbert, Boulter, & Rutherford 1998, p. 189). The most recent changes have seen the pendulum swing back, with a greater emphasis on NOS within the stated aims of the science curriculum, where students will “develop understanding of the nature, processes and methods
of science” and be “equipped with the scientific knowledge required to understand the uses and implications of science, today and for the future” (Department for Education, 2013, p.144).

A study of these reports, reform documents and curricula would show that ensuring students have an understanding of NOS has been one of the most consistent and central elements of science education reform over the last 20 years (Abd-El-Khalick et al., 2008; Duschl, 1990; Hodson, 2008, 2009a; Millar & Osborne, 1998; Southerland et al., 2007) and that NOS as a requirement of scientific literacy, is now clearly established as an important learning objective of science curricula in many countries. The need for an understanding of NOS as a requirement of scientific literacy is also well argued in the research literature (e.g., Abd-El-Khalick & BouJaoude, 1997; Clough, 2011; Hodson, 2008, 2009a; Lederman & Zeidler, 1987; Matthews, 2000, 2012; Shamos, 1995; Turner & Sullenger, 1999).

Indeed, the importance given to NOS in official curriculum documents has become so evident that Dagher and BouJaoude (2005) have stated: “improving students’ and teachers’ understanding of the nature of science has shifted from a desirable goal to being a central one for achieving scientific literacy” (p. 378).

However, in spite of a general and long-term philosophical commitment to this goal, the vast majority of research literature forces the conclusion that the goal has not yet been fulfilled. Part of the problem can be attributed to a justifiable confusion about just what the nature of science is (Lawson, 1999).

Defining the Nature of Science

The nature of science is a complex notion. A specific definition for NOS that philosophers, historians, scholars of science and science educators agree upon has been elusive. There have been various definitions proposed and changed as science and science education have changed. In the early 20th century, an understanding of the scientific method was thought to be synonymous with NOS (Central Association for Science and Mathematics Teachers, 1907; Hurd, 1960; Welch, 1979). John Dewey (1916) argued that familiarity with scientific method is substantially more important than acquisition of scientific knowledge, particularly for those who do not intend to study science at an advanced level. However, the existence of ‘the’ scientific method’ is now regarded as a myth of the nature of science.

If representations of science change in response to changing priorities, problems and situations, then it follows that our understanding of NOS will also change. This change in NOS can also be seen by considering the works of philosophers such as Popper (1959), Kuhn (1970) and Lakatos (1970). For example, Popper asserted that scientific knowledge is progressive, advancing cumulatively through a series of what he called conjectures and refutations. In contrast, Kuhn contended that scientific advancement is not evolutionary, but rather that it is a series of peaceful interludes, where scientists work within the existing paradigm (‘normal science’), punctuated by “intellectually violent revolutions where one paradigm is replaced by another” (Kuhn, 1970, p. 10). Lakatos, in turn, argued
that paradigms do not shift in revolutionary fashion, but only after years of dedicated scientific work and the weight of much evidence. Laudan et al. (1986) conclude:

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. We did once have a well-developed and historically influential philosophical position, that of positivism or logical empiricism, which has by now been effectively refuted. We have a number of recent theories of science that, while stimulating much interest, have hardly been tested at all. And we have specific hypotheses about various cognitive aspects of science, which are widely discussed but wholly undecided. (p. 142)

Echoing Laudan’s view, Stanley and Brickhouse (2001) noted, “although almost everyone agrees that we ought to teach students about the nature of science, there is considerable disagreement on what version of the nature of science ought to be taught” (p. 47). In seeking to capture what it is that should be taught, Clough (2006) has described NOS as “issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors” (p. 463). Such a description is informed by various studies of science including, but not limited to, the history, sociology and philosophy of science combined with research from the cognitive sciences such as psychology (McComas et al., 1998). Furthermore Clough and colleagues assert that, although there is a lack of complete agreement regarding what science is and how it works, significant consensus exists regarding fundamental issues in the nature of science relevant to science education (McComas et al., 1998).

McComas and Olson (1998) found in their review of eight leading national science education standards and curriculum documents, such as Benchmarks for Scientific Literacy and others from New Zealand, Canada, the United Kingdom and Australia, a “clear consensus regarding the nature of science issues that should inform science education” (p. 48) and be included in the school science curriculum, further summarised by McComas, Almazroa and Clough (1998) as:

- Scientific knowledge while durable, has a tentative character
- Science relies heavily, but not entirely, on observation, experimental evidence, rational arguments and scepticism
- There is no one way to do science (therefore, there is no universal step-by-step scientific method)
- Science is an attempt to explain natural phenomena
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws, even with additional evidence
- People from all cultures contribute to science
• New knowledge must be reported clearly and openly
• Scientists require accurate record keeping, peer review and replicability
• Observations are theory-laden
• Scientists are creative
• The history of science reveals both an evolutionary and revolutionary character
• Science is part of social and cultural traditions
• Science and technology impact each other
• Scientific ideas have been affected by their social and historical milieu. (p. 513)

This apparent consensus is somewhat incongruous given the lack of assent amongst philosophers, historians, scholars of science and science educators regarding a single description of NOS. This apparent accord in science education documents should still be seen within the reality that NOS remains a much-contested domain.

Perhaps the most recognised and widely used list of descriptors of NOS is that first penned by Lederman in 1992. Lederman carried out a comprehensive review of the empirical literature (both quantitative and qualitative) from the previous 40 years on students’ and teachers’ conceptions of NOS. From this review he argued that, although the NOS has been defined in numerous ways, it most commonly refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent in the development of scientific knowledge.

He then elaborated on this broad definition by identifying characteristics of NOS accessible to K-12 students and relevant to their daily lives, arguing that, although there is no clear consensus on a specific definition for the ‘nature of science’, there is general agreement among scholars on several fundamental aspects, particularly in terms of the level considered appropriate for K-12 instruction, where many of the disagreements about the definition or meaning of the NOS that continue to exist among philosophers, historians, and science educators are irrelevant (Lederman, 1992). Among the characteristics of the scientific enterprise corresponding to this level of generality are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory-laden), necessarily involves human inference, imagination and creativity (involves the invention of explanations) and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between, scientific theories and laws (Lederman, 2007; Lederman & Abd-El-Khalick, 1998).

Lederman maintains that, beyond these general characterisations, no consensus presently exists among philosophers of science, historians of science, scientists and science educators on a specific definition
for NOS (Lederman, 1998; Lederman, Antink, & Bartos, 2012). These seven descriptors, or tenets, have been repeatedly cited and widely used in research studies by others, including Abd-El-Khalick, Akerson, Bell, Crawford, Khishfe, J. Lederman, Schwartz, Wade and Zeigler, over the last two decades. They are the most generally used in assessment tools, including the range of VNOS tools designed by N. Lederman and J. Lederman.

Lederman and Lederman draw a distinction between NOS and scientific inquiry (SI). In a recent essay they discuss how during the 1980s, ‘scientific knowledge’ was dropped from the original label of the construct of NOS and ‘nature of science’ was used to refer to the same idea as ‘nature of scientific knowledge’. This, they argue, has led to the conflating of nature of science and SI (Lederman & Lederman, 2012, p. 336). They see a clear delineation between the two constructs where NOS refers to the characteristics of scientific knowledge that are directly derived from the process/method, the scientific inquiry used to develop the knowledge. Also, they contend that SI includes the traditional science processes (such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data), but also that it refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. The contemporary view of SI advocated is clearly not the narrow and distorted view of as a single scientific method, but rather “that the questions guide the approach and the approaches vary widely within and across scientific disciplines and fields (e.g., descriptive, correlational and experimental)” (p. 337).

Lederman has repeatedly signalled that the tenets of NOS he has proposed are not meant as a comprehensive listing and acknowledges that there are aspects that others include or delete with equal validity. His intention is not to emphasise one list above another (Lederman, 2007).

Before being specific about NOS, it is important to stress that we (my colleagues and fellow researchers) are not advocating a definitive or universal definition of the construct. We have never advocated that our ‘list’ is the only list/definition. Unfortunately, readers have read past our words (Irzik & Nola, 2011; Lederman, 2007; Matthews, 2012) and think we are stressing more than we are. Debates about a ‘definitive’ description of NOS abound, but are hardly productive. What we prefer readers to focus on are the understandings we want students to have. The understandings need not be limited to those we have selected. (Lederman et al., 2012, p. 2)

**Beyond a Consensus View**

Most science educators acknowledge that issues regarding NOS are still not settled (e.g., Abd-El-Khalick, et al., 1998; Clough, 2006; Clough & Olson, 2008; Eflin, Glennan, & Reisch, 1999; Matthews, 1994; McComas et al., 1998; Smith, Lederman, Bell, McComas, & Clough, 1997). Early empirical evidence challenging a consensus view comes from the work of Alters (1997a), who
surveyed the views of 210 members of the US Philosophy of Science Association. The purpose of his study was to investigate whether the tenets that science education literature explicitly and implicitly advocates, are also held by philosophers of science (Alters, 1997a). Responses to his 20-item Likert-type questionnaire on “15 tenets of NOS” led him to conclude that “the implication for the science education research community and its formal organizations is that we should acknowledge that no one agreed-on NOS exists” (p. 48) and that the tenets that are advocated as basic criteria for science education’s NOS must be reconsidered so that more accurate criteria may be developed. However, the methodological design and wording of some questions within Alters’ work have been strongly contested (Smith et al., 1997) – and refuted by Alters. One criticism was that the voices of other interested and knowledgeable parties, such as sociologists and historians of science and scientists themselves, were absent in Alters’ sample.

This latter concern was addressed by Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) who drew the 23 participants for their Delphi study from the communities of leading and acknowledged international experts of science educators; scientists; historians, philosophers, and sociologists of science; experts engaged in work to improve the public understanding of science; and expert science teachers. The study sought to determine the extent of agreement among participants from the ‘expert community’ on what ideas-about-science should be taught in school science. Although there was some dissimilarity among participants, the outcome of the research was a set of nine themes capturing key ideas about NOS for which there was consensus, and which were considered to be essential components of any school science curriculum:

- science and certainty
- analysis and interpretation of data
- scientific method and critical testing
- hypothesis and prediction
- scientific creativity
- science and questioning
- cooperation and collaboration
- historical development of scientific knowledge
- diversity of scientific thinking.

These themes show marked similarity to the conclusions of McComas and Olson (1998).

Almost two decades ago, Loving (1997) expressed concern with a consensus view of NOS and a list of tenets. She cautioned against oversimplifying NOS, suggesting that, in the same way that we ask that science not be taught in its final form, similarly NOS should not be taught without attention to what it takes for philosophers, historians and sociologists of science to arrive at their views of how
science is done – or how it should be done (see p. 447). She suggested a balanced approach which involves “being aware of varying positions on the nature of science and viewing Western science – when well done – as more of a loose configuration of critical processes and conceptual frameworks, including various methods, aims, and theories all designed to shed light on nature” (p. 437) and all viewed within the context of a human endeavour that is both interpretive and tentative.

**NOS as questions**

Clough’s (2007) concerns are not that an appropriate level of consensus for science education does not exist, but rather that these NOS tenets, like any list of key ideas, may easily be misinterpreted, distorted and misused by researchers, teachers and students. Tenets, like established scientific knowledge, can easily become something to be transmitted as additional declarative knowledge rather than investigated, something to know rather than understand. He reiterates the concern of Eflin et al. (1999): “Just as science educators stress that science is more than a collection of facts, we emphasize that a philosophical position about the nature of science is more than a list of tenets” (p. 112). While agreeing that NOS tenets might provide guidance for curriculum development, teaching, and assessment regarding the NOS, Clough and Olson (2008) stress that they must not dictate the scope and sequence of NOS teaching and learning. Effective teaching and assessing of NOS requires of teachers a much broader understanding than a list of NOS tenets. They maintain that since most, if not all, statements about NOS are contextual, with important exceptions, it follows that even where consensus does exist, “the key is to explore the NOS so that science teachers and students come to deeply understand its contextual nature” (p. 144). The purpose is not to indoctrinate, but to educate students about relevant issues, their contextual nature, and reasons for differing perspectives (Matthews, 1997).

To this end, Clough (2007) proposes that tenets be rephrased and used as questions such as:

- In what sense is scientific knowledge tentative[^3]? In what sense is it durable?
- To what extent is scientific knowledge empirically based (based on and/or derived from observations of the natural world)? In what sense is it not always empirically based?
- To what extent are scientists and scientific knowledge subjective? To what extent can they be objective? In what sense is scientific knowledge the product of human inference, imagination, and creativity? In what sense is this not the case?
- To what extent is scientific knowledge socially and culturally embedded? In what sense does it transcend society and culture?

[^3]: This question exemplifies the justification for framing NOS understanding around questions rather than tenets. The tentative nature of scientific knowledge must be understood within the context of the durability of scientific knowledge, supported by many lines of confirming evidence. Superficial acceptance of the tenet of the tentative nature of scientific knowledge can be taken to mean that rigorously established and very stable scientific knowledge can be simply discarded if it doesn't fit in with an individual’s anecdotal experiences or belief systems.
• In what sense is scientific knowledge invented? In what sense is it discovered?
• How does the notion of a scientific method distort how science actually works? How does it accurately portray aspects of how science works?
• In what sense are scientific laws and theories different types of knowledge? In what sense are they related?
• How are observations and inferences different? In what sense can they not be differentiated?
• How does private science differ from public science? In what ways are they similar?

Reshaping tenets as questions in this way may encourage teachers and students to address more deeply the contextual character of NOS ideas. Reframing as questions rather than tenets immediately raises issues of complexity as opposed to a rhetoric of statements, and invites discussion and understanding rather than straightforward acceptance. John Locke wrote in his 1689 Essay Concerning Human Understanding:

> The floating of other men’s opinions in our brains makes us not one jot more knowing, though they happen to be true. What in them was science is in us but opinionatry, whilst we give up our assent only to reverend names, and do not, as they did, employ our own reason to understand those truths which gave them reputation. Such borrowed wealth, like fairy money, though it be gold in the hand from which he received it, will be but leaves and dust when it comes to use. (1689/1924, p. 40)

**Situated NOS**

Hodson disagrees with Lederman and colleagues’ (2003) demarcation between SI and NOS. Rather he contends that restricting the use of NOS to epistemological considerations is unusual “given that much of our scientific knowledge and, therefore, consideration of its status, validity and reliability is intimately bound up with the design, conduct and reporting of scientific investigations” (Hodson, 2009a, p. 21). The conduct of scientific inquiry and epistemological considerations are related conceptually, procedurally and pedagogically.

This relationship between NOS and SI is reflected in Hodson’s definition of NOS, (along with that of others including Clough, 2006, 2011; Clough & Olson, 2008; Hodson, 2008, 2009a; Osborne et al., 2003; Wong & Hodson, 2009a, 2010) which embodies “the characteristics of scientific inquiry, the role and status of the scientific knowledge it generates, how scientists work as a social group, and how science impacts and is impacted by the social context in which it is located” (Hodson, 2009a, p. 21). This notion of NOS is broader than that afforded by a list of tenets and includes aspects “that are heavily value-laden, relate to gender and ethnic bias, address topics with a substantial moral-ethical dimension, and so on” (2009a, p. 71).

Hodson, as elaborated in Wong and Hodson (2010), concurs with Elby and Hammer (2001) who have
argued that the current consensual list of NOS items is too general, and that it is neither valid nor productive of good learning about science. A sophisticated epistemology does not “consist of blanket generalizations that apply to all knowledge in all disciplines and contexts; it incorporates contextual dependencies and judgments” (Elby & Hammer, 2001, p. 565). Recent work in history, philosophy, and cognitive studies of science suggests that, while certain generic features of science may cut across disciplines, different areas of science develop their own contextualised epistemic norms and heuristics (Kuhn, 1977; Laudan, 1990; Thagard, 2004). This he aligns with Rudolph’s (2000) argument that teachers should acknowledge the context dependency of scientific practice and knowledge generation:

Educators need to begin to exploit the vast literature of the science studies community, not to develop some universalist picture of science, the value of which is questionable, but to begin to understand what the various practices of science look like in all their myriad forms, in order to provide some reasonably authentic context in which to situate the scientific knowledge claims of the curriculum. (p. 409)

Wong and Hodson (2009, 2010) have looked at scientists’ descriptions of their research and their day-to-day practices within the science community to identify prominent features of NOS embedded in authentic scientific inquiry and to provide a view of science that can be compared and contrasted with the explicit and implicit images portrayed in school science textbooks and curricula, and with the views advocated by science educators (e.g., Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Osborne et al., 2003). The premise is that scientists themselves, working at the frontiers of science, can play a significant role “in refining and developing science educators’ views about the practices of the science community, the nature of scientific work, the aims behind it, and the interrelationships with the society in which it is embedded” (Wong & Hodson, 2009, p. 112). Examination of these practices will readily demonstrate that there is no single set of NOS elements which would fit all disciplines, contexts and time periods. Indeed different sub-disciplines of science employ distinctive styles of argumentation, rules of evidence and criteria of judgment, as well as different methods of collecting data (Wong & Hodson, 2009). Mayr (1997) contends that NOS views incorporated into science curricula are nearly always derived from physics. Biology, he reasons, is markedly different in many respects. For example the falsificationist scrutiny that operates well in most areas of physics is not suitable for the testing of probabilistic theories, which include most theories in biology (Mayr, 1997). Authentic views of the plethora of scientific practices, across the different disciplines of science, challenge the potential ‘one size fits all’ interpretation of NOS tenets.

**Features of science**

As Matthews (2012) sees it, the positive side of a list of tenets is that it puts NOS into classrooms; it provides researchers with an assessment tool; and it can give teachers and students some NOS matters to consider and become more knowledgeable about. However, he shares the concern of others that
such a list, despite the wishes of its creators, can become another ‘something to be learnt’. Rather than promoting the critical thinking which lies at the core of the rationale for including NOS, such a list can short-circuit critical thinking altogether.

Indeed Matthews recommends a change of terminology and research emphasis from the nature of science, which he describes as essentialist and epistemologically focused, to a “more relaxed, contextual and heterogeneous “Features of Science” (FOS)” (2012, p. 4). He argues that science has many features, “cognitive, social, commercial, cultural, political, structural, ethical, psychological, etc.” and that different science disciplines will be more useful than others in making clear different features. He also contends that other knowledge-acquiring enterprises can also share these features, to a greater or lesser degree (or not at all). It follows then that it is more accurate and useful to understand NOS not as some list of necessary and sufficient conditions for a practice to be scientific, but rather as something that, following Wittgenstein’s (1953) terminology, identifies a “family resemblance” of features that warrant different enterprises being called scientific (Matthews, 2012, p. 4). What holds together diverse sciences is not a set of unique characteristics, or tenets, shared by all sciences, but rather this family resemblance.

These FOS fit well within the purpose of nature of science education, which is not to indoctrinate but to address reasons for accepting a particular position. They can be elaborated, discussed and inquired about, rather than be NOS items to be learnt and assessed. Furthermore, Matthews (2012) argues that since these are features, rather than philosophical demarcation criteria, there are numerous other epistemological, historical, psychological, social, technological and economic features which can also be said to characterise scientific endeavour – and meet Lederman and Lederman’s (2012) three criteria of accessibility to school students; consensus among historians; and usefulness. Some of the features he proposes are: experimentation; idealisation; models; values and socioscientific issues; mathematisation; technology; explanation; world views and religion; theory choice and rationality; feminism; realism; and constructivism.

Matthews (2012) contends that this change of terminology and focus avoids philosophical difficulties with NOS such as the conflating of epistemological, sociological, psychological, ethical, commercial and philosophical features into a single NOS list. It also addresses contemporaneous NOS-related educational issues such as the idea that NOS understanding can be assessed by students’ ability to identify some declarative statements about NOS.

**Analogy of tenets as doors**

More than a decade ago, Rudolph (2000) advocated that educators should accept that no single nature of science exists and to develop curricula that help students understand instead the diverse, local practices that are found within and across scientific disciplines. Around the same time, Alters (1997a)
argued that although there is a broad range of philosophical positions on the nature of science, science educators typically underrepresent the range of epistemic positions in the philosophy and history of science. What is still needed a decade later is not a consensus definition and description of NOS, but rather a consensus that no one agreed-on NOS exists.

Tenets of NOS should not be seen as the end-points of understanding, but they can be seen as doors – a means to open the way to a deeper understanding. *Door* as a metaphor is powerful since a door represents a transition from one environment (here the environment of an understanding of NOS that has been informed/misinformed by an individual’s experiences of school science, and by the images of science promoted by popular culture and media) to another environment (here of a more informed understanding). They, doors/tenets, serve to represent the starting place for leaving one environment of understanding about science and entering a much broader conceptualisation of NOS in a wide range of authentic science practices.

Doors move us along from one place to another in the same way that, ideally, there is a progression, a deepening, and a broadening of understanding of NOS as students move through their science education. The Irish saying that, “Questioning is the door of knowledge” is apt here as it is only by asking questions of NOS that students will gain understanding. It is not possible to give young children a ‘once and for all NOS’, a sophisticated NOS understanding up front – just as it is not possible to give a sophisticated understanding of science content knowledge in final form. Rather, children should be taught as sophisticated a view as is needed at the time to be useful for them in understanding scientific practice. This level of understanding of practice changes over time. Clearly, the understanding they need when they leave school is totally different from what they need as young children. Matthews (2012) makes the same point when he states that students have “to crawl before they can walk, and walk before they can run. This is no more than commonsensical pedagogical practice” (p. 21). So it is educationally sound to teach at the level of understanding that helps students here and now, but it also leaves open the door so that their NOS understanding can change and develop to become more sophisticated and qualified. This becomes a reflective and critical development of understanding. As Feynman aptly spoke concerning knowledge and uncertainty, “[i]n order to make progress, one must leave the door to the unknown ajar” (1999, p. 149).

**Rationale for Teaching NOS**

Rationale for the emphasis on teaching NOS takes various forms. Driver et al. (1996), for example, as part of their research project looking at students’ images of science, propose utilitarian, democratic, cultural, moral and science learning arguments: understanding NOS is necessary to make sense of science and manage the technological objects and processes in everyday life; understanding NOS is necessary for informed decision-making on socioscientific issues; understanding NOS is necessary to
appreciate the value of science as part of contemporary culture; understanding NOS helps develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society; and understanding NOS facilitates the learning of science subject matter.

Similarly, McComas et al. (1998) offer a multi-faceted rationale for NOS pedagogy that includes utilitarian, democratic, cultural, and moral components. According to their argument, students who understand NOS are better able to make sense of science and technology, participate in socioscientific decision-making, value science as central to the development of our culture, and understand the moral commitments of scientists. These commitments can be instrumentalised by the larger society, where citizens should be able to use their NOS understanding to have influence on science through science policy and development.

Scholars have long described NOS understanding as an integral component of the broader construct of scientific literacy (Laugksch, 2000; Shamos, 1995; Schwab, 1962). Since scientific literacy is seen as comprising knowledge about science as well as knowledge in science, and since the first of these involves the epistemology and sociology of science, both of which are considered NOS perspectives, the centrality of NOS is clear. Indeed an understanding of NOS is at the heart of virtually all definitions of scientific literacy (McComas et al., 1998). Although extensive discussion of the term ‘scientific literacy’ is beyond the scope of this chapter, a brief discussion is warranted on the grounds that the rationale for teaching for scientific literacy can also be seen as rationale for teaching NOS. Understanding the underlying epistemic values, methods, and practices of science is essential if citizens are going to engage with the issues that confront society (Osborne et al., 2003).

The OECD’s Programme for International Student Achievement (PISA) proposes that scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity (OECD, 1999, 2003). Scientific literacy refers to an individual’s understanding of the characteristic features of science as a form of human knowledge and enquiry; awareness of how science and technology shape our material, intellectual, and cultural environments; and willingness to engage in science-related issues and with the ideas of science, as a reflective citizen (OECD, 2006).

Choi, Lee, Shin, Kim, and Krajcik (2011) developed a framework for scientific literacy for South Korea that includes five dimensions: content knowledge; habits of mind; character and values; science as a human endeavour; and metacognition and self-direction. The framework stresses integrated

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4 Clarification of the term ‘scientific literacy’, particularly for school science programmes, has been provided by a variety of science educators and organisations – see for example, AAAS, 1989a; Arons, 1983; Bybee, 1997; Choi et al., 2011; DeBoer, 2000; Dillon, 2009; Feinstein, 2011; Fensham, 2004; Gilbert, 2010; Hodson, 2008, 2011; Koballa, Kemp, & Evans, 1997; Laugksch, 2000; Mayer & Kumano, 2002; Miller, 1998; Millar & Osborne, 1998; National Research Council [NRC], 1996; National Science Board, 1998; Osborne, 2007; Roberts, 2007a; Ryder, 2001; Shamos, 1995).
understanding of big ideas and the importance of character and values. It emphasises an interpretation of global citizenship that encapsulates character and values that can lead learners to make appropriate choices and decisions to ensure a sustainable planet and provide all people with basic human rights. This framework is more akin to Hodson’s (2008, 2009a, 2011) view that to be fully scientifically literate, students need to be able to distinguish among good science, bad science and non-science, make critical judgments about what to believe, and use scientific information and knowledge to inform decision-making at the personal, employment and community levels – that is, they need to be critical consumers of science. Inherent within this understanding of scientific literacy is recognising that scientific text is a cultural artefact, and so may not be neutral in underlying interests, values, power, class, gender, ethnicity and sexual orientation (2008). Hodson (2011) argues for a critical scientific literacy, the fundamental purpose of which is to help people think for themselves and reach their own conclusions about a range of issues that have a scientific, technological and/or environmental dimension and advances that critical scientific literacy is a driving force for sociopolitical action.

From these definitions of scientific literacy, the rationale for teaching scientific literacy becomes clearer. Therefore the rationale for teaching NOS also becomes clearer. Taber (2010) proposes that this is an urgent imperative for various reasons including: increasing the number of talented young people choosing to enter science (and therefore contributing to economic development); countering a perceived conflict between science and non-science/anti-science; and ensuring responsible public decision-making in areas of major economic, technological and environmental importance. He argues that school leavers should be ready to be critical readers, savvy consumers, and informed voters, who are able to evaluate scientific claims and arguments (Taber, 2012).

Along the same lines and by using extensive and diverse literature, Thomas and Durant (1987) categorised the rationale for promoting the place of scientific literacy in education according to nine alleged benefits. These benefits are to science itself; national prosperity; national power and influence; individuals; democratic government; society as a whole; intellectual life; aesthetic appreciation; and morality. They stress that such classification is overly simplistic but suggest that it retains merit as a guide to a complex literature and as a basis for discussion. These arguments can be grouped broadly into three categories, (i) perceived benefits to science, (ii) benefits to individuals, and (iii) benefits to society as a whole (Hodson, 2011).

Benefits to science itself are seen in terms of increased new recruits into science-based professions; greater public support for science; and a lessened risk of loss of confidence, cynicism, disillusionment and eventual withdrawal of support for science, each of which are contingent on some general public understanding and valuing of what scientists do, how they do it, and the public’s right to debate how science should be used. There is growing concern among scientists (both in corporate and government
institutes) and educators that the general public lacks an adequate understanding of the nature and purpose of science, a lack that is most evident during national, and local debates over controversial issues such as evolution, climate change, and stem cell research (Cavanagh, 2008). Thomas and Durant (1987) suggest that an understanding of scientific literacy would also militate against the unrealistic and unreasonable expectations of science. For example, Rudolph (2007) discusses how the general public erroneously thinks that good science is based on controlled experiments, and acceptable scientific conclusions are those that are ‘proven’ by testing. This narrow view of NOS allows individuals to ignore or cast aside fundamental science ideas in areas as diverse as global climate change or astronomy because they rely on methodologies that go beyond experiments.

Concerning benefits to individuals, Thomas and Durant report the claim that scientifically literate individuals are likely to have access to a wider range of employment opportunities. They are also likely to be more able to negotiate their way effectively through the social world by being better equipped to make personal decisions about science-informed issues. This utility argument suggests that an understanding of science is practically useful in everyday contexts such as being able to draw upon knowledge of human nutrition in following a balanced diet; making choices in the face of conflicting and often specious ‘scientific’ claims in areas as everyday and diverse as weight-loss schemes, disease cures, alternative treatments such as iridology or aromatherapy; determining the credibility of information on the Internet; dismissing belief in astrology and other pseudosciences; interpreting media reports to inform personal and public decision-making concerning topical issues, such as mammogram recommendations; claimed links between autism and the measles vaccine; cellphone use and brain tumours and the like. Our students have to be able to distinguish between scientific assertions and just plain bad science; to be able to assess simple evidence; to understand whose expertise is more credible; to know what kind of conditions warrant a change in scientific consensus; to understand where verifiable evidence ends and value judgements begin (Allchin, 2011). They need a critical scientific literacy with a robust core understanding of NOS.

It is also argued that there are intellectual, aesthetic, and moral benefits of scientific literacy to individuals, that “science is an intellectually enabling and ennobling enterprise” (Schibeci & Lee, 2003, p. 188). It is generally accepted that knowledge of science is an important element of what it means to be an educated person today (e.g., Choi et al., 2011; Laugksch, 2000; Osborne, 2012). Promotion of scientific literacy therefore contributes to the promotion of intellectual culture itself since science is as central to a truly cultivated mind as literature, music and the performing arts.

Benefits to society are seen as two-fold: economic and democratic. The economic benefit is based on the assumption that national wealth is determined in part by economic success in international markets, and that success in such markets is based in part upon vigorous research and development programmes for the generation of new goods and services which, in turn, depends in part upon a
steady supply of scientists, engineers and technicians. The democratic argument maintains that democracy is upheld when all citizens are able to ask fundamental questions, analyse and challenge accepted norms, make judgments, use critical thinking and solve problems and can remain interested in scientifically related issues. Conversely, if the general citizenry remain scientifically illiterate, uninformed and/or disinterested, the privileged with access to the requisite knowledge stay privileged, and the scientifically illiterate remain powerless and marginalised (Keske, 2002). Ignorance of the way science works can easily be used by special interest groups, politicians, and corporations to cast doubt on scientifically well-supported ideas in areas such as climate change, so that these groups’ economic, social, and personal interests may be preserved.

This democratic argument is illustrated by Southerland, Golden and Enderle (2012) who use snippets of survey data from the United States to support the idea that not only is public understanding of science critical but, equally as significantly from a democratic/civil rights viewpoint, that issues of equity emerge within that domain in the differential statistical results that are seen across categories of race, gender, and socioeconomic status. For example:

Persons with lower socioeconomic status (SES) have disproportionately higher cancer death rates than those with higher SES, regardless of demographic factors such as race/ethnicity. (American Cancer Society, 2010, p. 38)
The rates at which diagnoses were made for respiratory ailments and other organ disorders, including diabetes, were severely disproportionate for different demographic groups. (Pleis et al., 2009)

The democratic rationale for teaching for scientific literacy aligns with the more radical rationale for scientific literacy in which community participation of individuals and collective praxis play important roles in making decisions on local and national issues and, therefore, provide the focus for what students will learn (Bencze, Alsop, & Bowen, 2009; Calabrese Barton, 2002). Here participation in collective activities fosters scientific literacy in a process of knowing as a distributed, situated, and dynamic process (Roth, 2003). Rationales such as these for scientific literacy can be seen in policy statements and science curricula in countries as diverse as Palestine (Wahbeh, 2003), Scotland (Education Scotland, 2010), England and Wales (Swinbank & Taylor, 2007), Brazil (Levinson, 2012), Portugal (Ferreira & Morais, 2011), the US (National Research Council, 1996), New Zealand (Ministry of Education, 2007a) and Australia (Australian Curriculum & Assessment Reporting Authority, 2012).

Hodson (2009a) accordingly advocates for a much more politicised and issues-based science education which can equip students with the capacity and commitment to take responsible action on matters of social, economic, environmental and moral–ethical concern. He persuasively communicates the necessity for scientific literacy with its core understanding of NOS, in the following passage with which this rationale for the nature of science section closes:
In short, why does it matter what image of science is presented and assimilated [in schools]? It matters insofar as it influences career choice, and so may have long-term consequences for individuals. It matters if the curriculum image of science is such that it dissuades creative, non-conformist and politically conscious individuals from choosing to pursue science at an advanced level. It matters if the image of science is such that it dissuades women, members of visual minority groups and students from lower socioeconomic status homes from entering science-related careers or seeking access to higher education in science and engineering because they do not see themselves included and represented in the science curriculum. It matters if our politicians, public servants and industrialists are so ignorant of scientific and technological issues that their decision-making is ill informed and uncritical. It matters if the general population is unable to respond logically and critically to the claims and proposals of those in society who might use scientific arguments (and sometimes pseudoscientifically spurious arguments) to persuade, manipulate and control. It matters if a significant part of humankind’s cultural achievement is poorly understood. Failing to provide every student with an adequate understanding of the nature of science runs counter to the demand for an educative citizenry capable of responsible and active participation in a democratic society. (Hodson, 2009a, pp. 142–143)

Are We There Yet?

Current views on NOS

NOS understanding, as one of the most consistent and central elements of science education reform over the last 40 years, has generated extensive research in assessing students’ and teachers’ views of NOS and has been the impetus for the development and implementation of curricula aimed at improving those views (Abd-El-Khalick et al., 2008; Akerson & Hanuscin, 2007; Bell, Blair, Crawford, & Lederman, 2003; Chen, 2006; Dogan & Abd-El-Khalick, 2008; Hodson, 2011; Khishfe, 2008; Lederman et al., 2002). However, this same body of research consistently suggests that despite the continuing discourse and efforts associated with science education reforms, these efforts have met with limited success as evidenced in multiple ways and in many reports (e.g., Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2009; Bora, Aslan, & Cakiroglu, 2006; Cavanagh, 2008; Sorenson, Newton, & McCarthy, 2012). Despite consensus on its importance, its criticality, it seems much remains to be done in moving the vision to a reality in the education of our students (Clough & Olson, 2012). So in a word, no, we are not there yet.

A significant number of research instruments, the most prominent being questionnaires, situated probes and interviews with both quantitative and qualitative perspectives, have been developed to assess students’ and teachers’ understanding about NOS in different countries and educational levels. Some of these are listed in Table 2.1. Various authors offer comprehensive reviews of these instruments and studies, including Lederman, Wade, and Bell (1998), Lederman (2007) and Hodson (2009a). In summary of his review of the research studies, Lederman (2007) states that after
approximately fifty years of research on NOS several generalisations can be made including that, irrespective of which instrument is used, K-12 students and teachers do not typically possess “adequate” conceptions of NOS (p. 841).

Table 2.1 Nature of science instruments

<table>
<thead>
<tr>
<th>Date</th>
<th>Instrument</th>
<th>Author(s)</th>
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</thead>
<tbody>
<tr>
<td>1954</td>
<td>Science Attitude Questionnaire</td>
<td>Wilson</td>
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<tr>
<td>1958</td>
<td>Facts about Science Test (FAST)</td>
<td>Stice</td>
</tr>
<tr>
<td>1959</td>
<td>Science Attitude Scale</td>
<td>Allen</td>
</tr>
<tr>
<td>1961</td>
<td>Test on understanding Science (TOUS)</td>
<td>Cooley &amp; Klopfer</td>
</tr>
<tr>
<td>1962</td>
<td>Processes of Science Test</td>
<td>BSCS</td>
</tr>
<tr>
<td>1966</td>
<td>Inventory of Science Attitudes, Interests &amp; appreciations</td>
<td>Swan</td>
</tr>
<tr>
<td>1966</td>
<td>Science Process Inventory (SPI)</td>
<td>Welch</td>
</tr>
<tr>
<td>1967</td>
<td>Wisconsin Inventory of Science Processes (WISP)</td>
<td>Literacy Research Center</td>
</tr>
<tr>
<td>1968</td>
<td>Science Support Scale</td>
<td>Schwirian</td>
</tr>
<tr>
<td>1968</td>
<td>Nature of Science Scale (NOSS)</td>
<td>Kimball</td>
</tr>
<tr>
<td>1969</td>
<td>Tests on the Social Aspects of Science (TSAS)</td>
<td>Korth</td>
</tr>
<tr>
<td>1970</td>
<td>Science Attitude Inventory (SAI)</td>
<td>Moore &amp; Sutman</td>
</tr>
<tr>
<td>1974</td>
<td>Science inventory (SI)</td>
<td>Hungerford &amp; Walding</td>
</tr>
<tr>
<td>1975</td>
<td>Nature of Science Test (NOST)</td>
<td>Billeh &amp; Hasan</td>
</tr>
<tr>
<td>1975</td>
<td>Views of Science Test (VOST)</td>
<td>Hillis</td>
</tr>
<tr>
<td>1976</td>
<td>Nature of Scientific Knowledge Scale (NSKS)</td>
<td>Rubba</td>
</tr>
<tr>
<td>1978</td>
<td>Test of Science Related Attitudes (TOSRA)</td>
<td>Fraser</td>
</tr>
<tr>
<td>1980</td>
<td>Test of Enquiry Skills (TOES)</td>
<td>Fraser</td>
</tr>
<tr>
<td>1981</td>
<td>Conception of Scientific Theories Test (COST)</td>
<td>Cotham &amp; Smith</td>
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<tr>
<td>1982</td>
<td>Language of science (LOS)</td>
<td>Ogunniyi</td>
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<tr>
<td>1987</td>
<td>Views on Science-Technology-Society (VOSTS)</td>
<td>Aikenhead &amp; Ryan</td>
</tr>
<tr>
<td>1990</td>
<td>Nature of Science Survey</td>
<td>Lederman &amp; O’Malley</td>
</tr>
<tr>
<td>1992</td>
<td>Modified Nature of Scientific Knowledge Scale (MNSKS)</td>
<td>Meichtry</td>
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<tr>
<td>1994</td>
<td>Repertory Grids</td>
<td>Lakin &amp; Wellington</td>
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<tr>
<td>1995</td>
<td>Critical incidents</td>
<td>Nott &amp; Wellington</td>
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<tr>
<td>1998</td>
<td>Views of Nature of Science B (VNOS-B)</td>
<td>Abd-El-Khalick, Bell, &amp; Lederman</td>
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<tr>
<td>1999</td>
<td>Questionnaire based on Newspaper Science Report</td>
<td>Murcia &amp; Schibeci</td>
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<tr>
<td>2000</td>
<td>Views of Nature of Science C (VNOS-C)</td>
<td>Abd-El-Khalick &amp; Lederman</td>
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<tr>
<td>2001</td>
<td>Views about Science Survey (VASS)</td>
<td>Halloun</td>
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<tr>
<td>2002</td>
<td>Views of Nature of Science D (VNOS-D)</td>
<td>Lederman &amp; Khishfe</td>
</tr>
<tr>
<td>2002</td>
<td>Thinking about Science Survey Instrument (TSSI)</td>
<td>Cobern</td>
</tr>
<tr>
<td>2003</td>
<td>Think-aloud protocols</td>
<td>Taylor &amp; Dana</td>
</tr>
<tr>
<td>2004</td>
<td>Views of Nature of Science E (VNOS-E)</td>
<td>Lederman &amp; Ko</td>
</tr>
<tr>
<td>2004</td>
<td>Open empirical investigation task, journals, interviews</td>
<td>Windschitl</td>
</tr>
<tr>
<td>2005</td>
<td>Students’ Epistemological Views of Science (SEVs)</td>
<td>Tsai &amp; Liu</td>
</tr>
<tr>
<td>2006</td>
<td>Views on Science &amp; Education Questionnaire (VOSE)</td>
<td>Chen</td>
</tr>
<tr>
<td>2007</td>
<td>Worldview &amp; Nature of Science Questionnaire (NOSQ)</td>
<td>Liu &amp; Lederman</td>
</tr>
<tr>
<td>2010</td>
<td>Pedagogical scenarios within open-ended questions</td>
<td>Guerra, Ryder &amp; Leach</td>
</tr>
<tr>
<td>2011</td>
<td>Interviews based on pedagogical scenarios</td>
<td>Buaraphan</td>
</tr>
<tr>
<td>2011</td>
<td>Knowledge of the Nature of Whole Science (KNOWS)</td>
<td>Allchin</td>
</tr>
</tbody>
</table>
Students’ views of NOS

An extended body of research indicates that the views held by students of NOS are not consistent with the contemporary conception of the scientific endeavour (including Cavanagh, 2008; Deng, Chen, Tsai, & Chai, 2011; Duschl, 1990; Lederman et al., 2002; Schwartz, Shapiro, & Gregory, 2013; Southerland et al., 2007). This is irrespective of country – for example Canada (e.g., Park, Nielsen, & Woodruff, 2014), China (e.g., Chai, Deng, Qian, & Wong, 2010), Greece (e.g., Stathopoulou & Vosniadou, 2007), South Africa (e.g., McCarthy & Sanders, 2007), South Korea (e.g., Park et al., 2013), Taiwan (e.g., Lin & Tsai, 2008), Turkey (Dogan & Abd-El-Khalick, 2008) and the US (e.g., Wenning, 2006). As discussed earlier, without a robust understanding of NOS, students cannot fully understand the role of science in society, will be left with simplistic or naïve views about science, and will be ill-equipped to make informed decisions as scientifically literate individuals.

Some researchers have suggested that one of the reasons why curricula have not completely succeeded in achieving their declared goals in relation to students’ understanding of NOS is that teachers’ ideas about NOS are also inadequate (e.g., Abd-El-Khalick et al., 1998; Carey & Stauss, 1968; Dogan & Abd-El-Khalick, 2008; Hodson, 1988; Lederman, 2007).

Teachers’ views of NOS

It is well established that, in general, many teachers possess inaccurate or simplistic views of NOS (Carey & Stauss, 1970; Lederman, 2007; Posnanski, 2010 and others) and are largely unaware of the social and cultural construction of scientific thought (Clough & Olson, 2012). Over 40 years ago Elkana (1970) stated that teachers’ views concerning NOS trailed contemporary philosophical views by more than two decades. Research studies assessing teachers’ understanding of NOS are consistent in showing that teachers generally do not possess informed conceptions of NOS, regardless of their academic ability or teaching experience (e.g., Akerson et al., 2006; Davis & Smithey, 2009). The irony of this situation is that, despite teachers’ intentions, their science teaching cannot escape conveying an image of NOS to students. Indeed, the views teachers hold will become the ‘hidden curriculum’ and will manifest in the messages teachers implicitly convey about science to their students in their talk about the subject, the content they select to teach, the type of activities they plan and the experiences they provide (Hodson, 2008).

This is because, ever-present in teaching are implicit and explicit messages regarding NOS. These messages can be seen in classroom practice, science curriculum materials, common cookbook laboratory activities – all of which generally ignore or downplay human influences in research, sanitise the work that has eventually resulted in accepted scientific knowledge, and portray science as a rhetoric of conclusions (Clough, 2011; Duschl, 1990; Rudge, 2000). So the issue becomes not whether teachers will teach about NOS, only what image will be conveyed to students.
Chiappetta, Ganesh, Lee, and Phillips (2006) noted that more than 90% of US secondary school science teachers rely on textbooks to organise and deliver instruction and assign homework. So rather than simply being one of several teacher resources, they suggest that, in the larger majority of senior-level classrooms, especially in North America, textbooks become the curriculum and determine to a much larger extent than desirable what is taught and learned about science. Over 50 years ago Kuhn (1962) observed that “[m]ore than any other single aspect of science, [the textbook] has determined our image of the nature of science and of the role of discovery and invention in its advance” (p. 143). More recently, Abd-El-Khalick, Waters and Le’s (2008) analysis of the representations of NOS in US high school chemistry textbooks, found textbooks fared poorly in their representations of NOS and that with a few exceptions, portrayal of NOS had either not changed or had actually become worse over the past four decades. At best, a few implicit and explicit messages about NOS were scattered throughout, but in many instances these messages were “propagating naïve views” (p. 851). There is little reason to believe that the treatment of NOS in textbooks of other science disciplines, or other countries would be substantially different (Irez, 2009; Meichtry, 1993; Richey, 2011). Textbooks all too often misrepresent facts as if they are without dispute, fixed and immutable, and with no sense of how these came to be, the frailty of human judgement or without the possibility of error (Hodson, 2008).

McComas (1998) identified 15 myths commonly included in science textbooks and classroom discourse. These are reproduced in Table 2.2 alongside a similar list identified by Hodson (1998) as common myths and falsehoods promoted, sometimes explicitly and sometimes implicitly, by the science curriculum. These significant misunderstandings regarding NOS interfere with deeply understanding science content and impact students’ attitudes toward science and science classes (Clough, 2011).
Table 2.2  Commonly promoted myths and falsehoods about science

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Hypotheses become theories that in turn become laws</td>
<td>Observation provides direct and reliable access to secure knowledge</td>
</tr>
<tr>
<td>Scientific laws and other such ideas are absolute</td>
<td>Science always starts with observation</td>
</tr>
<tr>
<td>A hypothesis is an educated guess</td>
<td>Science always proceeds by induction</td>
</tr>
<tr>
<td>A general and universal scientific method exists</td>
<td>Science comprises discrete, generic processes</td>
</tr>
<tr>
<td>Evidence accumulated carefully will result in sure knowledge</td>
<td>Experiments are decisive</td>
</tr>
<tr>
<td>Science and its methods provide absolute proof</td>
<td>Scientific inquiry is a simple algorithmic procedure</td>
</tr>
<tr>
<td>Science is procedural more than creative</td>
<td>Science is a value-free activity</td>
</tr>
<tr>
<td>Science and its methods can answer all questions</td>
<td>Science is an exclusively Western, post-Renaissance activity</td>
</tr>
<tr>
<td>Scientists are particularly objective</td>
<td>The so-called ‘scientific attitudes’ are essential to the effective practice of science</td>
</tr>
<tr>
<td>Experiments are the principal route to scientific knowledge</td>
<td>All scientists possess these attitudes</td>
</tr>
<tr>
<td>Scientific conclusions are reviewed for accuracy</td>
<td></td>
</tr>
<tr>
<td>Acceptance of new scientific knowledge is straightforward</td>
<td></td>
</tr>
<tr>
<td>Science models represent reality</td>
<td></td>
</tr>
<tr>
<td>Science and technology are identical</td>
<td></td>
</tr>
<tr>
<td>Science is a solitary pursuit</td>
<td></td>
</tr>
</tbody>
</table>

In addition to these messages about NOS within classrooms, there are strong messages about science on daily display in newspapers, on television and over the Internet, where socio-scientific issues such as climate change, genetically modified crops, global warming, and so on are reported and debated. News reports feed science information into the public domain. But these reports are not agenda neutral. They could be carrying out a “democratic watchdog role” (Russell, 2010, p. xvi), scrutinising the practices of government, business, interest groups and scientists themselves, or it could be that the world-view of the powerful is being privileged (McClune & Jarman, 2012). Either way, there will always be implicit and/or explicit messages about NOS. This also raises issues of media literacy and the place this should have in students’ education.

The NOS misconceptions held by science teachers, their students, and the general public, presented in popular media, promoted in textbooks and resource materials, and taught in classrooms, coalesce to form a powerful self-supporting network that continues the cycle of misconceptions, misunderstandings, distrust and disinterest generation after generation. So, we certainly are not there yet.

**Where to Next?**

*Teachers as change agents*

There is widespread consensus that effective teachers are the critical factor for student learning (Akerson, Buzzelli, & Donnelly, 2010). This is a positive finding. To be able to convey to students
appropriate conceptions of NOS, teachers must have adequate conceptions of NOS themselves (Tairab, 2001). It is safe to assume that teachers cannot possibly teach what they do not understand (Shulman, 1987). Therefore, teachers’ beliefs and knowledge may be regarded as a crucial leverage point to effect a change in the classroom. Teachers must hold views of NOS that are sufficiently extensive and critical to be able to determine what NOS to teach at each level. Looking ahead, developing teachers’ understanding of NOS must be a priority.

However, studies have also indicated that, even if a teacher has a sound understanding of NOS, there is not necessarily a direct translation of this into practice. This translation of a teacher’s conception of NOS to their teaching practice and to students’ understanding of NOS is a complex process. Such studies have indicated a variety of personal and contextual factors mediating or constraining the translation, including teachers’ perceptions of their students’ interest in, and ability to internalise ideas about NOS (Lederman, 1995; Zembylas, 1998); pressure to cover content (Hodson, 1993; Schwartz & Lederman, 2002); constraints of the curriculum (Hodson, 2011); other curriculum imperatives (Hipkins, Barker, & Bolstad, 2005); classroom management and organisational issues (Abd-El-Khalick et al., 1998; Hodson, 1993); teachers’ perceptions of their students’ interest in, and ability to internalise ideas about NOS (Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Zembylas, 1998); teachers’ beliefs about the importance of their students’ learning about NOS (Lederman, 1999; Lederman, Abd-El-Khalick, & Bell, 2001); lack of availability of instructional materials, teaching and learning resources, and assessments related to NOS (Hanuscin, Lee, & Akerson, 2011); and both teachers’ and students’ subject matter knowledge (Akerson et al., 2010; Schwartz & Lederman, 2002). Simply possessing valid conceptions of NOS does not necessarily result in the use of effective teaching approaches which lead to improved students’ conceptions of NOS (Lederman, 1992).

It is suggested that to effect translation into practice, what is needed is pedagogical content knowledge of NOS in addition to content knowledge of NOS. Effective teachers are those who are skilled in transforming their own subject knowledge into sequences of varied learning experiences (acknowledging what is known to be already familiar to learners) to help learners construct personal knowledge that shifts towards the target knowledge represented in curriculum models (Taber, 2010). Shulman (1987) first used the term “pedagogical content knowledge” (PCK) to describe this interwoven pedagogical and subject matter knowledge necessary for good disciplinary teaching.

Pedagogical content knowledge identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (Shulman, 1987, p. 4).

PCK for science has been explored by many, and debate about its definition and development continues (Abell, 2007; Kind, 2009). Several knowledge frameworks for science teaching have since
been developed, based on Shulman’s work (e.g., Abell, 2007; Appleton, 2006; Gudmundsdottir, Reinertsen, & Nordtømme, 1995; Hashweh, 2013; Magnusson, Krajcik, & Borko, 1999) and Shulman’s categories have continued to provide a useful tool for researchers, assisting them to identify distinctions in teacher knowledge that make a difference for effective teaching (Ball, Thames, & Phelps, 2008).

Based on Shulman’s framework, an effective teacher must have not only a firm understanding and knowledge of NOS, but also knowledge of effective pedagogical practices relative to NOS. They must also have the intentions and abilities to merge these two elements in the classroom (Schwartz & Lederman, 2002). Within this framework, it follows that possessing a rich understanding of NOS is a necessary, but insufficient condition, for effectively teaching NOS to students – just as possessing extensive substantive knowledge will not necessarily ensure effective teaching of science content. Furthermore, a teacher who is skilled in teaching children about the products of science, the content, will not necessarily also be good at teaching about NOS.

Appleton (2006) argues that PCK is a dynamic and developing form of knowledge. Central to his model of PCK development for primary teachers are ‘activities that work’: science activities described by other teachers or located in resources. In this model, primary teachers use their pedagogical knowledge, knowledge of students and existing science PCK to transform activities that work into personal PCK. In some ways Appleton’s activities that work are similar to Loughran’s description of PCK as ‘Cases’ in secondary education (Loughran, Berry, & Mulhall, 2006). Both emphasise the contextually developed nature of PCK.

The PCK needed for specifically teaching NOS is less well researched. Kim, Ko, Lederman, and Lederman (2005) found that even teachers confident enough in their understanding to teach NOS explicitly, did not necessarily employ a student-centred approach. These teachers taught NOS separately from other content, almost in rote fashion, reflecting what is often seen with new teachers lacking confidence and teaching experience. Such teaching may be a necessary intermediate stage in NOS PCK development, which may then develop further through a process of critical reflection. Further understanding of the ways teachers develop NOS subject matter knowledge (SMK) for science, i.e., epistemic knowledge of science, and develop effective methods for teaching it (NOS PCK) are needed if implementation of curricula with a focus on scientific literacy is to be successful.

As discussed, the implementation of effective NOS teaching is militated by a raft of factors. The lack of development in students’ understanding of NOS has also been related to problems arising from poor curriculum development processes. A good example of this can be seen in South Africa, where a curriculum initiative designed to incorporate modern educational trends, including NOS, failed to consider issues such as a largely un- or under-qualified workforce of science teachers, huge class
sizes, the extent of the changes they were asking for, and the over-zealous timeframes for implementation (Chisholm, 2000). Curriculum reforms, e.g., of NOS, must be accompanied by teacher professional development programmes that provide teachers with the necessary PCK of NOS. Successful NOS teaching will rely upon teachers being confident and supported by a flexible repertoire of resources. In terms of where to next, it is clear that there is a need for well-supported development of teachers’ and preservice teachers’ PCK of NOS, in order to provide the motivation to address the factors for translation into classroom practice (Bartholomew, Osborne, & Ratcliffe, 2004).

Implicit vs. explicit NOS approaches

NOS-specific pedagogical approaches for teaching students, preservice or inservice teachers, have fallen broadly into two groups: implicit and explicit. Advocates of the implicit approach suggest that an understanding of NOS can be achieved tacitly through participating in science-inquiry activities and process skills instruction that are consistent with the construct. It is assumed that learners gain understanding of epistemological meanings whilst engaged in ‘doing science’. However, empirical research has provided little evidence for the effectiveness of implicit approaches on learning of NOS (e.g., Bell et al., 2003; Khishfe & Abd-El-Khalick, 2002; Sandoval & Morrison, 2003).

For example, Bell et al.’s (2003) study looked at NOS conceptions of high school students involved in an 8-week scientific research apprenticeship with mentor scientists. The majority of students showed no improvement in their understanding of NOS, despite substantial gains in their understanding of the particular process skills they performed as part of their respective research projects. Similarly, Sandoval and Morrison (2003) have described the effects that students’ inquiry during a 4-week unit on evolution and natural selection had on their beliefs about the nature of science. Using pre- and post-NOS interviews they found that students’ epistemological ideas did not appear to change and suggested that students’ inquiry experiences had little influence on their understanding of NOS without explicit attention being paid to epistemological ideas. They contend that doing and talking science are not the same as talking about science and argue for the crucial role of an explicit epistemic discourse in developing students’ NOS understanding.

More recently, in separate studies, Hsu, van Eijck and Roth (2010) and Yacoubian and BouJaoude (2010) used pre-test–post-test control-group design to compare the development of NOS views in inquiry-based laboratory activities between the control groups who received implicit inquiry-based instruction and the experimental groups who engaged in the same inquiry activities but included also explicit and reflective discussions to make “the ‘invisible’ aspects of scientific laboratory work ‘visible’ for students” (Hsu et al., 2010, p. 1263). Both studies reported that explicit inquiry-based instruction enhanced students’ views of the target NOS aspects more than implicit inquiry-based instruction alone which did not substantially enhance the students’ target NOS views at all. These
researchers also concluded that involving students in authentic science activities is not sufficient for students to develop representations of authentic science. Analogously, research also indicates that teaching the history of science without explicit NOS instruction does not seem to impact learners’ NOS views (Abd-El-Khalick & Lederman, 2000a; Abd-El-Khalick et al., 2008; Solomon, Scott, & Duveen, 1996).

In contrast to an implicit approach, an explicit approach proposes that NOS needs to be overtly addressed as a cognitive instructional outcome of science lessons, activities, inquiry-based investigations, and discussions and must be “planned for instead of being anticipated as a side effect” (Akindehin, 1988, p.73). Here NOS understanding is regarded as specific and tangible curriculum content with instructional outcomes that should be intentionally targeted in the same manner that abstract understandings associated with scientific theories, such as atomic theory, are intentionally targeted (Donovan-White, 2006). An explicit pedagogical approach to teaching NOS involves intentional, purposeful instruction of NOS, discussions, inquiry activities, NOS-relevant questioning in the context of activities, investigations, historical examples, and analogies, and guided reflection to help learners develop NOS understanding. This should not be confused with a didactic instruction nor taken to imply the imposition of the particular views of the teacher upon the students. It does require rejection of the view that NOS understanding can be acquired by students as a by-product of engaging in other science activities (Hodson, 2011).

Empirical support has been obtained for the effectiveness of the explicit approach in enhancing learners’ understanding of NOS as is evidenced by a range of studies, including a critical review of the research on NOS instruction from Abd-El-Khalick and Lederman (2000a) who concluded that explicit approaches have been more consistently effective than implicit approaches. More recent empirical support is seen with preservice teachers and other undergraduate majors (e.g., Abd-El-Khalick & Akerson, 2009; Abd-El-Khalick & Lederman (2000b), Abd-El-Khalick (2005); Akerson & Donnelly, 2008; Hanuscin, Akerson, & Phillipson-Mower, 2006). Inservice teachers also have been shown to improve their NOS views with professional development involving explicit instruction on NOS (e.g., Akerson, Hanson, & Cullen, 2007; Akerson & Hanuscin, 2007; Hanuscin et al., 2011; Morrison, Raab, & Ingram (2009); Schwartz & Lederman (2002). Other studies with students taught using an explicit approach, show similar results (e.g., Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Sandoval & Morrison, 2003; Schwartz et al., 2002).

Thus, a broad range of studies indicates that it is explicit instruction which holds substantial potential to develop rich NOS understandings. For example, in a study that directly compared implicit and explicit inquiry approaches to NOS instruction, Khishfe and Abd-El-Khalick (2002) investigated sixth graders’ NOS understanding before and after a 10-week intervention. Students who experienced the implicit instruction retained their initial conceptions about NOS. In contrast, those students who
experienced the explicit instruction demonstrated substantially ‘improved’ NOS views. Other significant studies include those showing the effectiveness of an explicit approach using historical case studies to engage students in the kinds of reasoning used by scientists originally struggling to construct satisfactory explanations and make sense of phenomena (Adúriz-Bravo & Izquierdo-Aymerich, 2009; Clough & Olsen, 2012; Rudge & Howe, 2009) and those which have shown the value of embedding explicit teaching of NOS within important socioscientific issues (e.g., Wong, Hodson, Kwan, & Yung, 2008; Wong, Kwan, Hodson, & Yung, 2009).

Within these studies it can be seen that effective explicit NOS instruction should not be direct teaching and transmission of information, nor the indoctrination of the teacher’s ideology of NOS. Rather it is the consequence of sufficient planning and design before the lessons so students may be appropriately alerted to NOS themes. It also requires recognising the opportunities to address relevant NOS ideas as they unfold in the classroom. Some researchers have noted that for teachers encultured in the habitus of traditional science teaching, this

would require a shift in their conception of their own role from dispenser of knowledge to facilitator of learning; a change in their classroom discourse to one which is more open and dialogic; a shift in their conception of the learning goals of science lessons to one which incorporates the development of reasoning and an understanding of the epistemic basis of belief in science as well as the acquisition of knowledge. (Bartholomew et al., 2004, p. 678)

Several authors caution against the tendency to instruct and assess student understanding based on its alignment with a prescribed set of views on the subject and instead reiterate an instructional commitment to student understanding absent of adopting any ‘one and only’ desirable view of science or the philosophical position of the teacher (Matthews, 2012; Smith & Scharmann, 2008). The goal becomes one of functional NOS for scientific literacy rather than knowledge of NOS tenets alone – the difference between reducing understanding to solely a cognitive outcome, as compared to a deeper and broader hermeneutic understanding where NOS ideas will be nuanced differently in different domains of science.

**Contextualised and decontextualised explicit approaches**

The general agreement that explicit NOS instruction is more effective than implicit approaches prompts questions about the format this explicit instruction should take, including the contrast between explicit teaching of NOS as non-integrated or as integrated with the process skills/science content being taught. In other words, it can be the focus of the lesson itself, with no direct links to specific science content (non-integrated) or it can be embedded within a variety of scientific contexts (integrated). This raises the interesting question of the role of context in facilitating the development of appropriate NOS conceptions.
Explicit non-integrated NOS instruction teaches NOS independently from teaching science content through the use of activities and discussion specifically designed to promote particular aspects of the nature of science, with no direct connection to science content or process skills. One such approach uses activities such as puzzle-solving activities (Clough, 1997), ‘black-box’ activities, and pictorial gestalt switches (e.g., see Lederman & Abd-El-Khalick, 1998) to explicitly introduce and draw students’ attention to important ideas about NOS. These activities have no science content, but are used as analogies to make explicit aspects of NOS or of scientific inquiry. It has been argued that teaching NOS and science content separately might distribute the cognitive load for students, in that NOS instruction is not complicated by new science content (Clough, 1997; Pollock, Chandler, & Sweller, 2002).

Explicit integrated NOS instruction uses authentic science contexts and asks students to consider what these illustrate about science and scientists. Specific examples of such integration include embedding NOS concepts within instruction about science content itself; instruction about the development of modern science ideas (e.g. conceptions of the structure of the atom, or the classification of species); instruction, argumentation and debate concerning socioscientific issues (SSIs); and embedding NOS concepts into the development of specific science process skills.

Embedding and teaching NOS in relation to specific science content is certainly integrated from a curriculum and a pedagogical point of view. It could be argued that the integration of NOS into content in a real world application or applying NOS within SSIs is a deeper level of integration or contextualisation. Integrating current socioscientific issues, the history of science, and contemporary science stories can powerfully contextualise NOS (e.g., Clough, 2006; Hodson, 2003, 2009a, 2011; Khishfe & Lederman, 2006; McComas, 2008; Walker & Zeidler, 2007). Teaching NOS in this highly contextualised manner is important in persuading teachers that NOS instruction need not detract from, and can likely promote, science content learning (Clough & Olson, 2008). If the goal is scientific literacy, then this capacity to appreciate NOS ideas in current socioscientific issues and in the historical development of scientific ideas is critical.

Gilbert (2006) describes context in science education by referring back to its Latin derivatives; the verb ‘contexere’ means ‘to weave together’ and the noun ‘contexus’ denotes ‘coherence’ and ‘connection’. So it is context that gives meaning, and should provide a coherent structural value for something new to be set within a broader perspective. Context-based education helps students see and appreciate more clearly the links between the science they studied and their everyday lives (e.g., Hofstein, Eilks & Bybee, 2010).

**Integrated or non-integrated NOS instruction**

There is, as yet, no clear consensus on whether NOS is best taught integrated or non-integrated,
contextualised or decontextualised. On the one hand it has been suggested that to separate NOS as non-integrated instruction adds yet another component to an already overcrowded curriculum, and must, in a sense, mean replacing science content material with units or modules of NOS. It is also suggested that isolating NOS issues may make it more problematic for students to make links between the same NOS ideas when they appear in different contexts (Taber, 2010). Some have cautioned that non-integrated instruction with its lack of authentic context, is unlikely to engender the robust understandings of NOS that would serve as a foundation for addressing NOS in the teachers’ own science instruction (Brickhouse, Dagher, Letts, & Shipman, 2000; Clough & Olson, 2001; Smith & Scharmann, 2008). Bell, Matkins and Gansneder (2011) note that research on situated learning (e.g., Brown, Collins, & Duguid, 1989) supports a cautionary stance on students’ ability to view the nature of science as an integral component of science when it is taught apart from what they perceive as ‘real’ science content.

On the other hand, although integrating teaching of NOS into the teaching of existing science topics intuitively seems a more promising approach, it will require careful planning and simply adding to the learning demand placed upon students by incorporating additional learning objectives into lessons may also be problematic when many students are already struggling to make sense of the scientific concepts themselves (Leach & Scott, 2002). From a situated learning perspective (Brown et al., 1989; Lave & Wenger, 1991) NOS learning is enhanced in authentic contexts. Authentic contexts can be those which link science to the students’ real world, or engage students with SSIs, or present them with scientists’ case studies. Schwartz and Lederman (2008) and Wong and Hodson (2009) recommend scientists’ case studies to provide rich examples of NOS from contemporary experiences in the scientific community. Such case studies will allow students to see that NOS is nuanced differently, not only by discipline, but rather by the specific contexts of individual inquiries and investigations of scientists. As noted earlier, NOS cannot be characterised as discipline-specific.

Throughout the history of science education, scholars and practitioners have called for the contextualisation of science content through the exploration of socially relevant issues. The Science-Technology-Society (STS) movement, originally established in the 1970s, and more recently expanding to Science, Technology, Society and Environment (STSE) education, has been the most widespread and recognisable movement within science education for prioritising the social significance of science. Over the last two decades, a newer framework has emerged for teaching and research associated with socially relevant science: SSIs. In their review of research reports looking at the effectiveness of SSI as contexts for science education, Sadler and Dawson (2012) found compelling evidence that the inclusion of SSI in science supports the development of science content knowledge, NOS understanding, interest and motivation and argumentation.

This and other research provides compelling evidence supporting the efficacy of SSI as contexts for
learning science and suggests that SSIs provide a rich context for enhancing students’ and teachers’ understandings of NOS (Hodson, 2011; Walker & Zeidler, 2007; Zeidler, Sadler, Applebaum, & Callahan, 2009). SSIs provide a powerful context in which teachers can integrate instruction about science content and NOS in ways that help “students envision the connection that exists between more global issues and themselves” (Sadler, 2004, p. 531) and has the potential to empower students and better prepare them to be informed decision-makers as adults (Driver, Newton, & Osborne, 2000).

There have been few research studies upon which to draw when considering the question of context in NOS instruction. Bell et al. (2011) reviewed six case studies which used explicit NOS instruction, contextualised or decontextualised, and found positive results were indicated in both contextualised and decontextualised approaches, and mixed or negative results were just as likely in either approach. Two studies have directly compared the effectiveness of contextualised and decontextualised approaches to NOS instruction; one with ninth-grade environmental science students (Khishfe & Lederman, 2006) and the second with high school students in biology, chemistry, and environmental science (Khishfe & Lederman, 2007). The findings of both of these studies suggest improvement in students’ conceptions of NOS, regardless of discipline or whether NOS instruction was taught within a contextualised or decontextualised approach.

Of interest too, is a third study, that of Bell et al. (2011), the purpose of which was to assess the relative impacts of explicit-versus-implicit NOS instruction as well as the relative efficacy of teaching NOS as an isolated topic versus teaching it as an integral part of a socioscientific issue – global warming (GW) and global climate change (GCC), with 75 preservice teachers enrolled in four sections of an elementary science methods course. Independent variables included instructional approach to teaching NOS (implicit vs. explicit) and the context of NOS instruction (as a stand-alone decontextualised topic vs. situated or contextualised within instruction about GCC and GW). These treatments were randomly applied to the four class sections along a 2×2 matrix, permitting the comparison of outcomes for each independent variable separately and in combination to those of a control group. The results of the investigation support the necessity of explicit NOS instruction since only the students in the groups receiving explicit NOS instruction made substantial gains in their understandings of NOS. These results are consistent with other recent investigations supporting the necessity of explicit NOS instruction.

The results in regard to context of NOS instruction were equally clear: students made substantial gains in their NOS understandings regardless of whether NOS instruction was situated within the socioscientific issue of GCC/GW or taught decontextualised. Teaching NOS without connecting it to a socioscientific issue was just as effective as teaching it as an integrated component of GCC/GW instruction. These results contrast with those of a previous investigation (Abd-El-Khalick, 2001).
However, teaching NOS within the context of GCC/GW did produce superior gains in the ability of the preservice elementary teachers to use their knowledge of NOS (rather than nonscientific factors) in decision making processes to justify energy policy. These results provide preliminary evidence that teaching NOS in the context of a socioscientific issue may be a successful strategy for facilitating students’ ability to apply their understandings of the nature of science in decision making. Science educators have argued that learning to use one’s conceptions of the nature of science in decision making is an important educational outcome in itself and, as such, warrants particular attention and explicit instruction (Hodson, 2011; Sadler, 2004).

The overall picture emerging from these results is that, while setting instruction in the context of authentic science content and issues may be desirable, it may not be necessary when the primary goal is for students to understand key aspects of NOS. However, the context in which NOS instruction is situated may be more important when the goal is to encourage teachers to incorporate NOS into their own instruction, and is certainly important if the goal is functional NOS for scientific literacy.

Clough (2006) builds on researchers’ prior recommendations and suggests that NOS instruction (explicit/reflective) should range from decontextualised to moderately and highly contextualised with extensive scaffolds back and forth along this continuum. He argues that decontextualised activities are extremely important from a conceptual change standpoint as they provide opportunities for teachers to confront and initiate students’ dissatisfaction with their misconceptions of NOS. Dissatisfaction with prior conceptions is one of the four conditions posited by Posner, Strike, Hewson and Gertzog (1982) as essential for conceptual change to occur. Since conceptual change is difficult to achieve, such decontextualised activities may serve a useful facilitative function.

They also provide an excellent scaffolding point into more abstract NOS ideas that may be intertwined within science content. However, they alone are not sufficient for students to develop a proficient scientific literacy (Clough, 2006; Clough & Olson, 2001). If exclusively used to portray NOS in science classrooms, students may well dismiss these activities simply as puzzle solving unless they are augmented with NOS experiences that are more contextualised within science content. So in addition to decontextualised activities, teachers must explicitly and reflectively teach NOS through highly contextualised examples. Through explicit/reflective highly contextualised NOS instruction, teachers can overtly draw students’ attention to the nature of science, thus reducing students’ abilities to see NOS as something divorced from science content – and working towards functional NOS for critical scientific literacy.

\[5\] This aligns with the approach of the New Zealand Curriculum (MOE, 2007a) where NOS is to be ‘threaded through’ the four contextual strands (Living World, Material World, Physical World & Planet Earth & Beyond) which provide the contexts for learning.
The role of reflection

A review of research studies indicates that the most effective of all approaches to teaching NOS are those that have a substantial reflective component (e.g., Abd-El-Khalick & Akerson, 2004; Akerson & Donnelly, 2010; Akerson & Volrich, 2006; Heap, 2007; Lotter, Singer & Godley, 2009; Schwartz, Lederman, & Crawford, 2004). Reflection on experiences within science, either in the classroom or in authentic settings, has been identified as a critical element necessary for formalising views of NOS. The extensive literature on conceptual change adds further support to the role of reflection (Abd-El-Khalick & Akerson, 2004; Strike & Posner, 1992) since improving NOS understandings is complex and, like any other science learning, requires an approach that addresses conceptual change (Clough, 2006). Findings from many studies over the past three decades show that students come into science instruction already holding deeply rooted conceptions and ideas about the phenomena and concepts to be taught – conceptions that are often inconsistent with science views or are even in stark contrast to them. This is as true for students’ epistemological understandings as it is for substantive knowledge.

It follows that NOS learning should be understood in terms of conceptual change theory (Smith & Scharmann, 2008). Literature reviewed by Schwartz (2004) suggests that in order to construct understanding of NOS, students need opportunities to engage in reflective activities and reflective discussions, to reflect upon and explain their ideas about NOS, to discuss the strengths and limitations of those ideas, to assess the consistency of their ideas with those of others and to reflect on their own views and on NOS aspects that occur within the context of a science-based activity or science content being learnt. Indeed, Schwartz (2004) has proposed that reflection on NOS, perhaps in conjunction with, and in direct reference to, inquiry activities in which the students are engaged may be the “critical pedagogical component” (p. 8) required for the successful teaching of NOS. Such reflection must be taught, explained, modelled and practiced if it is to move beyond mere description (though often a very detailed description) to a deeper and well-considered analysis of learning experiences, activities, events and issues (Coll et al., 2011).

The significance of incorporating reflective elements in teaching NOS lies in making learning more meaningful and effective. Baird (1998) claims that if students are encouraged to ask and answer evaluative questions, then the cognitive and affective outcomes of learning also improve. Furthermore, reflection in a group context, in addition to contributing to meaningful and effective learning, is significant from a social view of learning (Yacoubian & BouJaoude, 2010). Reflective group discussions contribute to students’ learning from each other, thus making NOS instruction even more explicit, whether NOS instruction is integrated, non-integrated, contextualised or decontextualised.
Concluding Thoughts

NOS related research studies frequently indicate as a limitation the short duration of the instruction, against the lengthy period time required to: a) effect change in NOS views and b) develop the PCK required for translation into practice. One such example is found in the results of Project ICAN: Inquiry, Context, and Nature of Science, a National Science Foundation-funded teacher enhancement project in the United States. The findings of the project clearly indicate that explicit instruction and continuing teachers’ support can develop the knowledge and instructional skills required to enhance students’ understanding of NOS, however, “such professional development takes an extended and continuous period of time” (Lederman & Lederman, 2012, p. 352). Findings such as these present a very real challenge, given the short time span of many preservice teacher education science courses and the limited professional development funding and opportunities for inservice teachers in science education. If it is not realistic, in the immediate future at least, to increase the duration of instruction, then it is incumbent upon preservice and inservice teacher educators to maximise effective instruction within the given, albeit short, timeframe.

If reflection on NOS is a key, then within our programmes maximum opportunities for reflection should be intentionally structured. Research studies have structured reflection in a variety of ways, including reflective discussion (Schwartz & Lederman, 2002), reflective journaling or journals-based assignments (Bell et al., 2003; Schwartz, 2004), interviewing practising scientists about their work (Morrison et al., 2009), using metacognitive strategies such as concept mapping, researching the development of their peers’ NOS understanding (Abd-El-Khalick & Akerson, 2009), and using authentic contexts and SSIs. Emerging research in the field of argumentation has provided some evidence to suggest that an understanding of the processes of argumentation could also aid the development of more informed understandings of NOS. Real world science is rich in claims, counter-claims, argument and dispute, while decision-making concerning SSIs requires evaluation of claims, information and opinion from a wide range of sources. It follows that students need to understand the kinds of knowledge claims scientists make and how they advance them. They also need to be able to address the arguments and counter-arguments within SSIs confidently (Hodson, 2011). Such informed argumentation will further support the reflection required to develop NOS understanding. Simmons and Zeidler (2003) posit that “using controversial socioscientific issues as a foundation for individual consideration and group interaction provides an environment where students can and will develop their critical thinking and moral reasoning” (p. 83).

Considering the short time-frame compels us to also consider the potential for learning with new technologies, such as Web 2.0 to facilitate the reflection required for NOS understanding. Web 2.0 is a term used to describe a second-generation form of the World Wide Web that emphasises collaboration...
and sharing of knowledge and content among users (McLoughlin & Lee, 2008). Social software has emerged as a major component of the Web 2.0 movement’s use of networked computing to connect people in order to boost their knowledge and their ability to learn. New media literacies (NML) is a theoretical framework that has been used to explore the uncommon participation opportunities made available through these emerging technologies. NML extends the traditional definition of literacy to encompass the practices of meaning making within social networks. Central to NML is a focus on collaboration, distributed expertise and authority, and collective or shared knowledge (Lankshear & Knoble, 2006). Unlike frameworks such as instructional technology, information technology, educational technology, and computer aided learning, all of which foreground the computing devices themselves, NML shifts the focus to the impact these emerging technologies have on socially constructed meaning-making. Here the focus is not the tool itself, but how the tool is employed in a specific context to enhance effective pedagogy.

NML and reform-based versions of science education for critical scientific literacy both represent a paradigm shift from the traditional, transmission model of learning. Luehmann and Frink (2012) propose that carefully designed engagement with Web 2.0 technologies could provide science teachers and learners with the learning and participation structures which are not common, or not possible, within traditional learning environments bounded by class periods and physical walls. In using Web 2.0, students have access to the ideas of other students and can attempt to consolidate these in order to improve their own understanding and to build the knowledge – in this instance, new collective and individual understanding of NOS – of the community of which they are a part (van Aalst, 2006).

The use of Web 2.0 can provide a structure to facilitate repeated and persistent opportunities for reflection; structured and guided opportunities for learners to examine their own views and identify the discrepancies between their NOS conceptions and those presented, and in doing so, address Schwartz’s (2004) assertion of reflection on NOS being the critical pedagogical component required for the successful teaching of NOS. This use of Web 2.0 technology is discussed further in Chapters 5 and 6.
Chapter 3: Structuring Reflection to Develop an Understanding of NOS

Introduction

An understanding of the nature of science as a crucial and core educational component of scientific literacy is widely argued in literature and is clearly reflected globally in science education documents and reform initiatives (e.g., Abd-El-Khalick & Lederman, 2000a; Hodson, 2008; Matthews, 2012; Osborne et al., 2003). The emphasis on an understanding of NOS has become so prominent over recent decades that most science educators describe it as a major goal of science education (e.g., Lederman, 2007; McComas et al., 1998; Southerland et al., 2007). Hodson proposes that universal critical scientific literacy (learning about science), “is one of the educational imperatives” to prepare students to manage life in our changing world (Hodson, 2008, p. 38). In New Zealand, The New Zealand Curriculum (2007) recognises this imperative in describing NOS as the “overarching unifying strand” and stating that “the core strand, Nature of Science, is required learning for all students up to year 10” (Ministry of Education, 2007a, pp. 28–29).

However, research studies to date have shown that teachers generally do not hold informed understandings of NOS regardless of their academic ability, academic background, or teaching experience (e.g., Akerson, Morrison, & McDuffie, 2006; Davis & Smithey, 2009). While it is acknowledged that a teacher’s valid, informed conceptions of NOS do not necessarily directly translate into teaching approaches that improve students’ conceptions, it is widely accepted that teachers’ views of NOS are critically important. To convey appropriate NOS conceptions to students, teachers must hold views of NOS that are sufficiently extensive and critical to be able to determine what NOS to teach at each level.

Teaching approaches to improve NOS can be seen as two broad groups: implicit and explicit. Defenders of the implicit approach propose that NOS understanding can be achieved tacitly through participating in science inquiry activities and process skills instruction that are consistent with the contemporary NOS understanding. However, empirical research does not generally support this claim (e.g., Bell et al., 2003, Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Sandoval & Morrison, 2003).

In contrast, an explicit approach proposes that NOS is not a side effect of science teaching, but rather must be planned for and overtly addressed as a cognitive instructional outcome of science lessons, activities, and discussions (Akindehin, 1988). Research studies to date have shown the explicit approach to be more effective than the implicit in improving learners’ conceptions of NOS (e.g., Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2007; Rudge and Howe, 2009; Schwartz et al., 2004).
Explicit approaches can be either non-integrated or integrated with the science content being taught. Explicit non-integrated NOS instruction teaches NOS independently from teaching science content, for example by utilising puzzle-solving activities (Clough, 1997), ‘black-box’ activities, and pictorial gestalt switches (e.g., see Lederman & Abd-El-Khalick, 1998) to explicitly introduce and draw students’ attention to important ideas about NOS. These activities have no science content, but are used as analogies to draw attention to aspects of NOS or of scientific inquiry. Teaching NOS and science content separately in this way, might distribute the cognitive load for students in that they are not trying to accommodate new learning about NOS and new science content simultaneously (Clough, 1997; Pollock et al., 2002).

Explicit integrated NOS instruction uses authentic science contexts to encourage students to consider what these illustrate about science and scientists. For example, integrating current socioscientific issues, the history of science, and contemporary science stories can powerfully contextualise NOS (e.g., Akindehin, 1988; Clough, 2006; Hodson, 2003, 2009a; Khishfe & Lederman, 2006; McComas, 2008; Walker & Zeidler, 2007). This capacity to appreciate NOS ideas in current socioscientific issues and in the historical development of scientific ideas is critical for the goal of scientific literacy. From the teachers’ perspective, teaching NOS in this highly contextualised manner is important in persuading them that NOS instruction need not be ‘more to cover’. Rather than detracting from, it can likely promote, science content learning (Clough & Olson, 2008). It also addresses the issues of time constraints that arise in approaches which are focused on adding NOS-related modules into already over-crowded curricula (Abd-El-Khalick, 2013).

Improving NOS understandings is complex and, like any other science learning, requires an approach that addresses conceptual change (Clough, 2006), particularly given the wealth of research studies which show that many students come into science instruction already holding deeply rooted conceptions and ideas about the phenomena and concepts to be taught – conceptions that are not always consistent with the science views or are even in stark contrast to them. Since the middle of the 1980s investigations of students’ conceptions at meta-levels, namely conceptions of NOS and views of learning (i.e., meta-cognitive conceptions) also have been given considerable attention. Research shows that students’ conceptions here are also rather limited and naïve (Duit & Treagust, 2003). Alternative conceptions of NOS are indeed commonly held – for example, the view of science as a fixed body of facts. (A concise summary of common alternative conceptions, or myths, can be found in Hodson 1998, and McComas 1998.)

Furthermore, it is well accepted that significant meaningful knowledge cannot be transmitted directly from teacher to student. It follows that NOS learning could be better understood in terms of conceptual change theory (Smith & Scharmann, 2008). The extensive literature on conceptual change emphasises that it is complex and difficult to achieve (Clough, 2006) and indicates the key roles of
reflection and metacognition in developing NOS understandings, suggesting that explicit, reflective instruction is necessary to address the misconceptions students hold (Abd-El-Khalick & Akerson, 2004; Akerson & Hanuscin, 2007; Peters & Kitsantas, 2010; Schwartz et al., 2004; Yacoubian & BouJaoude, 2010). Schwartz (2004) has proposed that reflection on NOS, perhaps in conjunction with (and with direct reference to), inquiry activities in which the students are engaged may be the “critical pedagogical component” required for the successful teaching of NOS (p. 8). Reflective approaches provide structured and guided opportunities for learners to examine their own views and in this case identify the discrepancies between their NOS conceptions and those presented. Therefore, the research design for this study incorporated an explicit reflective approach, generic science-content-free NOS activities and both integrated and non-integrated approaches.

Framing the NOS concept

While ‘nature of science’ is often used by science educators to refer to issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists function as a social group, and how society influences and reacts to scientific endeavours (Clough & Olson, 2008), there is no mutually agreed upon, universally accepted ‘definition’ of NOS. In this research study, Lederman’s (1998, 2002) widely used and cited tenets of NOS were adopted as an initial starting place for discussion, questioning and developing NOS understandings, and also as a framework for data analysis. However, it should be stressed here that in order to accurately and effectively teach and assess NOS, teachers’ understanding about NOS must certainly go well beyond any list of NOS tenets. Mathews (2012) recommends a change of terminology from the essentialist and epistemologically focused ‘nature of science’, to a “more relaxed, contextual and heterogeneous ‘Features of Science’ (FOS)” (2012, p. 4) – a “family resemblance” of features that warrant different enterprises being called scientific (Matthews, 2012, p. 4) rather than a set of defined unique characteristics. He posits, however, that a list of tenets does at least put NOS into classrooms and can provide researchers with an assessment tool. To this end, in the current study tenets were used as a starting place for these teachers, and as an assessment tool for the researcher.

Purpose of the research study

The purpose of this research was to identify significant features in the development of teachers’ views of NOS, and to identify factors that contributed to this development. Two factors in this process of change are examined:

- the role of structured reflection
- the structuring of a course to combine an integrated and a non-integrated approach using generic NOS activities.
It was intended that this research would contribute to the debate on whether NOS is better taught embedded within the science content (integrated) or as a separate ‘pull-out’ topic (non-integrated) (Lederman, 2007).

**Research Design**

The research was embedded in critical social science methodology since the emphasis placed on transformation, emancipation, and change underpins both critical social science and the educational goal of scientific literacy and NOS. This research project was seen as having this potentially transformative, emancipatory function for the participants involved (i.e., the teachers enrolled in the course) as individuals who understand NOS aspects can attain a level of scientific literacy that enables them to ask fundamental questions, analyse and challenge accepted norms, make judgements, and solve problems in scientifically related issues. Such individuals are empowered to function within and change society (Keske, 2002). The researcher was both instructor and researcher and consequently the research design exhibits the complexity of the duality of teaching and researching.

The participants were practising teachers enrolled part-time in a Bachelor of Education programme in a semester-long science methods course to upgrade their Diploma of Teaching qualifications. Sixteen were teaching at the primary level, eight at early childhood level and one was teaching early childhood educators. Their teaching experience ranged from 6 to 25 years.

**Course design**

Since understanding NOS requires conceptual change rather than the acquisition of a superficial awareness of a few NOS tenets, it therefore follows that a course design and pedagogy were required that acknowledged the current level of conceptual understanding of each participant, and provided repeated opportunities for reflection.

Although most NOS research studies to date have generally adopted either an integrated or non-integrated approach, the design of this research provided the opportunity for both in each session from the onset to the conclusion of the course. Explicit integrated instruction occurred throughout the teaching in each of the science content areas, with course content being used overtly to draw attention to NOS. For example, the tentative nature of scientific knowledge was explored within the context of the history of the development of the theory of plate tectonics in the geology component of the course, and was debated within the socioscientific issue of climate change during the astronomy component (Planet Earth & Beyond). Non-integrated instruction occurred when generic science-content-free NOS activities (referred to henceforth as ‘generic activities’), such as those developed by Lederman and Abd-El-Khalick (1998), were used during the course as decontextualised, stand-alone activities.
**Integrated–non-integrated continuum**

As in Khishfe and Lederman’s 2006 study which compared NOS instruction for integrated and non-integrated groups, NOS instruction was distributed throughout the course to allow multiple exposures to NOS and to create multiple opportunities for participants to make links between epistemological and conceptual ideas (Khishfe & Lederman, 2006). In each science context area (topic), NOS was taught primarily as integrated with the science content. However, within most topics, at least one generic activity was also utilised. This was strategically placed in the session content so that it could be related to the science content, but no links were made by the lecturer between the generic activity and the science content. The opportunity for connection was available to be made by the participants if they were able to do so. Thus, teachers who had sufficient conceptual understanding of the NOS tenet(s) in the activity, and of the science content being covered at the time, were able to contextualise the NOS tenet(s) within the content being taught for deeper conceptual change.

This strategic placement meant that the embedded generic NOS activities could be engaged with by the participants as non-integrated pull-out activities (Lederman, 2007) or, alternatively, as a NOS activity closely related to the context. This structure provided a cognitive space within which the teachers could learn in a non-integrated or an integrated way depending on their own understanding of the science content and NOS ideas (Clough, 2006).

**Scaffolding for reflection**

Reflection and conceptual learning was facilitated by a course design that encouraged active participation in both practical experiences and theoretical approaches and promoted social interaction in small groups (Abd-E1-Khalick & Akerson, 2004). To facilitate initial reflection, the teachers completed 20 selected questions from the Views on Science-Technology-Society (VOSTS) questionnaire (Aikenhead & Ryan, 1992) in the second session of the course. The questionnaire was used for two reasons: first, to gather data about the teachers’ existing NOS views; second, to encourage the teachers to consider the wide range of views presented as multiple-choice options to each of the VOSTS questions. It was hoped that this exposure to the multiple views presented as possible responses in the VOSTS questionnaire would prompt deeper reflection on the teachers’ own views from the outset of the course.

Throughout the course, teachers were asked to reflect on science content and NOS in their regular journal writing during class time. Writing in journals enabled them to ‘converse with themselves’ and created a powerful means of exploring beliefs, attitudes, and learning. It also played a major metacognitive role, requiring the teachers to assess what they were learning, reflect upon it, and gain insight into their own understanding. One of the findings from Project ICAN (Lederman & Lederman, 2005) was that a student-centred approach with frequent reflective and interactive conversation is
more effective in shifting NOS views than short and didactic discussions on NOS at the end of the lesson. Consequently, this course was structured to encourage teachers to make journal entries at any time during the sessions as well as at a set time at the end of each session. These journals created a repository of developing ideas about NOS for subsequent analysis. By providing multiple opportunities for the teachers to display their views, a more accurate mapping of their understanding was possible.

Since active reflection should be purposeful and specific, question prompts were used to probe, elicit, and clarify the teachers’ understanding of NOS in more depth. Initially the prompts, ‘What significant learning has occurred for me today?’ and, ‘What ideas about science have changed for me in this session?’ were used to facilitate this reflection. It was thought that the second of these two questions would prompt reflection on NOS and yield NOS-related comments. When over the first three full-day sessions this did not happen, the prompts were modified to be more specific and direct; that is, ‘What science have I learnt?’ and ‘What have I learnt about the nature of science?’ The lecturer/researcher took time to model reflective practice by recording on the whiteboard some examples of reflective responses that could be appropriate for the two prompts. (No teachers used these modelled responses in their own journal writing.)

**Course overview**

Table 3.1 shows the structure of the course – in particular, the science context areas (topics) covered, the placement of the generic activities, the NOS tenets overtly addressed, and where the data-gathering tools were used. Data collection was continuous throughout the course. The shaded boxes indicate the tenets that were explicitly covered during each of the contexts and during each of the generic activities undertaken. The contexts are numbered to show their chronological order. The course was 5 months in duration, with a combination of full-day and three-hour sessions totalling 40 hours of instruction. Detailed descriptions of the generic activities used can be found in Lederman and Abd-El-Khalick (1998) and Chambers (1983).
### Table 3.1 Overview of course structure

<table>
<thead>
<tr>
<th>Course content</th>
<th>Science context</th>
<th>Generic NOS activities</th>
<th>NOS tenet addressed</th>
<th>Data gathering tools used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tentative</td>
<td>Empirical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Subjective/theory laden</td>
<td>Inferential/imaginative/creative</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Socially &amp; culturally embedded</td>
<td></td>
</tr>
<tr>
<td><strong>Commencement of course</strong></td>
<td></td>
<td></td>
<td></td>
<td>Open-ended questions</td>
</tr>
<tr>
<td>1 Introductory Investigations</td>
<td></td>
<td></td>
<td></td>
<td>VOSTS</td>
</tr>
<tr>
<td>2 Plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Electricity</td>
<td></td>
<td>Tricky Tracks</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Draw a Scientist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Physical &amp; Chemical Properties</td>
<td></td>
<td>That’s Part of Life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Physical &amp; Chemical Properties</td>
<td></td>
<td>The Whole Picture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Geology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Continental Drift</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Astronomy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Conclusion of course</strong></td>
<td></td>
<td></td>
<td></td>
<td>Open-ended questions</td>
</tr>
</tbody>
</table>

### Data Collection

As shown in Table 3.1, data on the teachers’ initial NOS views were collected using an open-ended questionnaire and selected items from the VOSTS questionnaire (Aikenhead & Ryan, 1992). The open-ended questionnaire asked the teachers to complete four statements: Science is....; Experiments are....; Ideas come from....; The skills needed by scientists are.... Throughout the course, data on developing understandings was gathered using the teachers’ reflective journals. Views were again collected at the conclusion of the course by repeating the initial open-ended questionnaire.

Using three data-collection tools enabled the researcher to map more comprehensively the existing and developing understandings of NOS held by the teachers, as no one single tool or test can perform all functions. This use of multiple tools allowed for the divergent aspects of the participants’ understandings of NOS to be exposed, and provided for substantiation of findings.

The data reported in this paper were obtained by analysing the pre- and post-questionnaires and the teachers’ journals. This was done using five NOS tenets as a conceptual framework for data analysis.
Counts were made only when a teacher’s response clearly and unambiguously expressed a particular NOS tenet. (A non-count could be considered ‘not expressed’ or ‘naive’, and a positive count ‘informed’ in the terms used in many other research studies.)

**Results**

Table 3.2 presents the teachers’ pre- and post-views using five NOS tenets as a framework for analysis. It shows the number and percentage of teachers whose open-ended questionnaire responses clearly and unambiguously indicated an understanding of a tenet.

**Table 3.2 NOS understandings indicated in pre- and post- open-ended question responses**

<table>
<thead>
<tr>
<th>Science is:</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of participants who clearly indicated NOS tenet</td>
<td>Percentage participants who clearly indicated NOS tenet</td>
</tr>
<tr>
<td></td>
<td>(n=25)</td>
<td>%</td>
</tr>
<tr>
<td>Empirically based</td>
<td>14</td>
<td>56%</td>
</tr>
<tr>
<td>Tentative</td>
<td>3</td>
<td>12%</td>
</tr>
<tr>
<td>Inferential/imaginative/creative</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>Subjective &amp; theory laden</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Socially &amp; culturally embedded</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

Analysis of the initial open-ended questionnaire showed that, at the outset of the course, the only NOS tenet expressed by more than 50% of the teachers was the empirical basis of science. Five (20%) of the teachers wrote about the creative and inferential NOS, and only three (12%) clearly indicated the tentative NOS. None of the teachers gave responses that could be categorised as representing an understanding of the subjective and theory-laden, or socially and culturally embedded NOS.

Table 3.2 shows that, in their post-programme questionnaire responses, each of the five tenets was expressed clearly by more teachers, with 18 teachers (72%) indicating an informed understanding of the empirical NOS and of the tentative nature of scientific knowledge; 16 (64%) indicating the inferential, imaginative, and creative NOS; 13 (52%) teachers indicating an appreciation of the subjective and theory-laden NOS; and 8 (32%) noting its social and cultural embeddedness.

Further analysis indicated that 24 of the 25 teachers were able to articulate an informed understanding of at least one NOS tenet in their written responses to the final open-ended questionnaire. Furthermore, 8 (32%) of these teachers clearly expressed informed understandings of all five selected

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6 In the tables and text throughout this thesis n indicates the number of participants.
NOS tenets. At the outset of the course, none of the teachers held informed views of all five of the target tenets of NOS.

**Monitoring the process of change using reflective journals**

As indicated earlier, the principal focus of this research was an examination of the role of reflection and generic activities in contributing to these teachers’ developing views of NOS. Developing views were monitored by analysing their journal entries for each of the science topics covered, as well as for each of the six generic NOS activities.

Table 3.3 shows the number of teachers who expressed a NOS tenet in their reflective journal writing in each topic and in each generic NOS activity. As in Table 3.1, Column A of Table 3.3 shows the topics covered during the course and Column B indicates the generic NOS activities used. Column C shows the number of teachers who communicated at least one NOS tenet in their journal writing during the activity or topic. Columns D–H identify which NOS tenets were expressed in the teachers’ journals. Multiple references by a teacher to the same NOS tenet during one context or one generic NOS activity tenet were scored as only one, since the analysis was to show how many teachers articulated each tenet not how many times each teacher expressed the tenet. Since the teachers may have articulated more than one tenet, the value for the total number of comments in each unit usually exceeds the value for the total number of teachers who commented in that topic. The shading of the cells (columns D–H) indicates the tenets that were explicitly taught during the topic or activity.
### Table 3.3 Teachers’ NOS expression in journal entries

<table>
<thead>
<tr>
<th>Science context</th>
<th>Generic NOS activities</th>
<th>NOS tenet addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number of teachers who expressed NOS tenet(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tentative</td>
</tr>
<tr>
<td>Introductory Investigations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Tricky Tracks</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Draw a Scientist</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties 1</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>That’s Part of Life</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>The Whole Picture</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties 2</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Geology</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>The Aging President</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Continental Drift</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>Young &amp; Old</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Astronomy</td>
<td></td>
<td>24</td>
</tr>
</tbody>
</table>

**Analysis of reflective journal entries**

Further analysis of the journal data revealed five particularly significant features concerning the shifts in understanding:

- the initial low level of responses to the NOS prompt
- the significant response to Tricky Tracks (the first generic NOS activity)
- the increasing NOS identification in the subsequent generic NOS activities
- the positive trend of NOS communications in content areas
- an increase in the complexity of communications.

Each of these five features will be discussed with reference to Tables 3.2 and 3.3 and using illustrative quotes from the teachers’ journal writing.

**The initial low level of responses to NOS prompt**

For each of the first three topics (Introductory Investigations, Plants, and Electricity) the journal writing prompts were:
What did I find significant today and why?

What ideas about science have changed for me in this session?

It was anticipated that, with the very explicit and repeated attention given to NOS throughout the sessions, some NOS-related comments would be given in response to the second prompt. However, Table 3.3 shows that this was not so. Only two of the 25 teachers gave a NOS-related statement during the Introductory Investigations topic, and only three teachers during the Plants and the Electricity topics, respectively.

During the Introductory Investigations topic, the two teachers who did write NOS-related reflections both commented upon the tenet of inference/imagination/creativity. For example:

When we tried to plan our investigation to compare the meat content of different brands of pie, I certainly had a window of insight into the creativity scientists must use to design investigations. An aha moment for me. (Lee, J, 1)

Once we had decided what to investigate there wasn’t just one way to do it. We all had different ideas. (Terry, J, 1)

However, aside from NOS comments by these two teachers, the journal entries for both prompts from the rest of the cohort focused on significant learning in content areas rather than on NOS. For example, in response to the second prompt:

Paper towels are made of cellulose fibres which is why they are so absorbent. (Miriam, J1,1)

The Electricity and Plants journal entries also revealed a focus on significant learning in the content area, diary recording of the session, or with a focus on teaching practice rather than related to NOS. The Introductory Investigations, Electricity, and Plants topics represented 20 hours of science teaching during which NOS was consistently made explicit and relevant to the content being covered and teachers were given plenty of opportunities for reflective writing in their journals. This absence of NOS responses during these three initial topics could be explained in several ways: unfamiliarity with reflective writing as a process; not understanding NOS; inability to differentiate between the science content and aspects of NOS being addressed; inability to articulate NOS understanding; or an insufficiently explicit prompt. Regarding unfamiliarity with journal writing, journal writing had been introduced, taught, discussed and modelled in the first session of this course. Given the initial low level of NOS comments, journal writing skills were revisited at this point with further teaching, discussion and critique of journal entries to highlight the difference between cursory or detailed descriptions and reflective analyses of the sessions and activities.

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7 The reference in parentheses after each quote identifies the teacher; the ‘J’ that it was a journal entry; and the number indicating which entry. So (Lee, J, 1) indicates that this quote is from the first entry in Lee’s journal. All names used are pseudonyms.
The significant response to ‘Tricky Tracks’: The first generic NOS activity

Tricky Tracks (Lederman & Abd-El-Khalick, 1998) was the first of six NOS generic activities used to highlight specific aspects of NOS by providing concrete experiences that were undertaken independent of any science content. Data suggest that its use proved to be a turning point. As shown in Table 3.3, this first NOS activity primarily made explicit the subjective/theory-laden NOS by illustrating the difference between observation and inference – that based on the same set of evidence (observations, or data), several explanations may be valid. The empirical NOS and the creative, imaginative, and tentative nature of scientific knowledge were also addressed in this activity. Table 3.3 shows that this activity was the first time the teachers’ journal reflections showed a significant number of NOS-related responses.

Eighteen teachers (72%) discussed the Tricky Tracks activity in their journals as significant learning that occurred for them that day. All 18 wrote comments that showed developing understanding of the inferential/imaginative/creative NOS. Thirteen of these 18 responses (72%) were also categorised as showing the empirical NOS.

For example:

I saw today the difference between observation and inference. So much of what I have previously thought of as observation, I see now is actually inference. ‘The leaves on the plant are drooping’ is an observation, but ‘I can see that that plant needs water’ is actually an inference. And all inference needs some creativity, imagination and existing ideas or theories to draw from. (Dale, J, 4)

All of the teachers reported on the Tricky Tracks activity in a non-integrated way – that is, although it was embedded in the electricity topic, teachers did not link the generic NOS activity with the NOS explicitly covered the science content of electricity. This could suggest that NOS may be easier to conceptualise when the students do not need to struggle with complex scientific concepts at the same time as they are trying to internalise new understanding of NOS.

Increasing NOS identification in the subsequent generic NOS activities

Table 3.3 suggests that each of the six generic NOS activities used was successful in scaffolding reflective NOS-related comments about their targeted NOS tenet. From Tricky Tracks on, the teachers recorded NOS tenets in their journals (although it should be acknowledged that this could be maturation- and time-related rather than due to the generic activities).

As with the Tricky tracks activity, most of the teachers commented only on the tenet(s) they saw in the generic activity. They did not relate any of the tenet(s) they saw to any of the science content being covered. That is, they approached the activities in a non-integrated pull-out fashion, totally separate from the science content learning of the session. However, a few of the teachers did link the NOS
tenets of the activity to the science content being covered. That is, they integrated the generic activity and the science content. This non-integrated vs. integrated reflection was seen, for example, in the ‘That’s Part of Life’ activity, which was carried out during the science content of the Physical and Chemical Properties (1) topic. This activity addressed the tenets of subjective/theory-laden NOS, inferential/imaginative/creative NOS, and socially and culturally embedded NOS. Most of the teachers reflected on the activities in a non-integrated way, just reflecting on the tenet(s) they saw in the activity without relating the tenet(s) to any of the tenets being made explicit in the science content of the same session. Nineteen of the teachers (76%) recorded at least one tenet of NOS from this activity. Eighteen of these teachers (72%) made a comment referring to the subjective and theory-laden nature of NOS. Examples of this:

We needed to already have an understanding of doing the laundry (~ the theory) before we could possibly make sense of the ‘That’s Part of Life’ activity (~data). Likewise scientists need existing theories, ideas, or knowledge to make sense of any data. Therefore it follows that science must be subjective – not the purely objective accumulation of facts about our world as I thought before. (Jess, J, 7)

When you understand the context then the explanation is meaningful. Scientists’ beliefs, previous knowledge and expectations can all affect how they interpret data. (Lindi, J, 7)

Some of the teachers, however, used the activity in an integrated way and related reflections on NOS activity to NOS ideas they saw in the science content being covered in the same session, or to previous content covered, without the lecturer making these connections. Kerrie, for example, showed a shift in her level of understanding and an integrated approach in that she was able to relate the NOS tenet of scientific observations as being subjective and theory laden, which in this activity she identified back to her drawing of the cross-section of a lily during the topic on Plants earlier in the course:

My understanding of the article about doing the washing was influenced by experiences I already have about doing the washing. My drawing of the cross section of the lily when we did Plants was influenced by what I remember from college biology classes. If I didn’t know what structures I was looking at, I don’t think I would have seen them as clearly. If I didn’t know about washing machines I couldn’t have made sense of That’s Part of Life. (Kerrie, J, 7)

Positioning the NOS activities so that they could be approached in an integrated or non-integrated manner allowed them to be used by the teachers at their own level of conceptual understanding to scaffold their reflections.

**The positive trend of NOS responses in content areas**

The data in Table 3.3 suggest the teachers found it more difficult to recognise NOS in content areas than in the generic NOS activities. After the first generic activity, Tricky Tracks, the expression of NOS tenets still decreased in the next topic (Physical and Chemical Properties). This occurred despite
the reflective prompts being changed to be more specific at the beginning of this topic session. Analysis of the journal entries (with the new prompt) for this topic showed that all teachers made pertinent comments under the heading ‘What science did I learn?’ But only 11 gave a NOS-related response to, ‘What did I learn about the nature of science?’ Most teachers gave science content-related, observational, or teaching practice-related reflections to the NOS prompt, as well as to the science content prompt. For example, as a response to ‘What did I learn about the nature of science?’ Dana stated:

   Salty water has a lower freezing point than pure water. (Dana, J, 6)

Only two teachers consistently differentiated between science content/observational entries and NOS entries.

However, when analysing the NOS reflections in each of the content areas covered (Plants, Electricity, Physical and Chemical Properties 1 & 2, Geology, Continental Drift, and Astronomy), an overall positive trend can be seen in the number of NOS reflections made by the teachers in their journals. As Table 3.3 shows, the Introductory Investigations topic saw two NOS comments made by two teachers, while the final topic, Astronomy, saw 81 comments made by 24 teachers.

An increase in complexity of responses

It is not possible to infer from the numerical data given in Table 3.3 how deeply or superficially the teachers held these NOS understandings. There are, however, three aspects of the data related to the complexity of the responses, which could be indicative of a shift in the level of understanding of this cohort of teachers as a whole. These three aspects are: increases in the length of the journal entries; the increase in the linking of tenets; and the increase in the number of responses when the tenet was not taught.

Increases in the length of responses

A direct relationship does not necessarily exist between length of response and complexity; a succinct response could be profoundly deep and complex. That said, analysis of the reflective journal entries does indicate an overall increase over the duration of the course in the length of many of the teachers’ responses when addressing a tenet. Comparison of Sam’s first journal entry on empirical NOS during Physical and Chemical Properties (Journal 6), with her final entry on empirical NOS during Geology (Journal 12), illustrates this trend.

   Observations are important in science. (Asha, J, 6)

   Science depends on observations – with any of our sense – and scientists can extend these observations with technologies like microscopes, telescopes, radar, thermometers etc. It
follows then that technology must often pave the way for new science. It was observations of similar coastlines, fossil records and undersea continental shelves that lead to the development of the theory of continental drift. Technologies like sonar and radar in WWII and measurement of magnetic data provided observations previously not possible. (Asha, J, 12)

This could suggest an increase in complexity of thought and/or an increase in ability to articulate a NOS understanding, or an increase in confidence to express it.

**Increase in the linking of tenets**

Analysis of the teachers’ reflective journals indicated that as the course progressed some teachers were able to make links and see the relationships between NOS tenets, rather than discussing them only discretely. This could suggest a deeper level of understanding and the genesis of a conceptual framework for NOS rather than adherence to a few discrete tenets. Table 3.4 shows the number of teachers who were able to make these links. It should be noted that these numbers represent the same group of teachers; the seven teachers for the last three topics were the same seven teachers each time.

**Table 3.4** Linking across NOS tenets

<table>
<thead>
<tr>
<th>Context</th>
<th>Number of teachers who linked NOS tenet(s) ($n=25$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Investigations</td>
<td>-</td>
</tr>
<tr>
<td>Plants</td>
<td>-</td>
</tr>
<tr>
<td>Electricity</td>
<td>-</td>
</tr>
<tr>
<td>Tricky Tracks</td>
<td>-</td>
</tr>
<tr>
<td>Draw a Scientist</td>
<td>-</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties 1</td>
<td>-</td>
</tr>
<tr>
<td>That’s Part of Life</td>
<td>1</td>
</tr>
<tr>
<td>The Whole Picture</td>
<td>3</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties 2</td>
<td>2</td>
</tr>
<tr>
<td>Geology</td>
<td>4</td>
</tr>
<tr>
<td>The Aging President</td>
<td>6</td>
</tr>
<tr>
<td>Continental Drift</td>
<td>7</td>
</tr>
<tr>
<td>Young &amp; Old</td>
<td>7</td>
</tr>
<tr>
<td>Astronomy</td>
<td>7</td>
</tr>
</tbody>
</table>

Sandy’s response, which illustrates this linking, linked two NOS tenets together in the ‘The Hole Picture’ activity. Sandy did not simply see two tenets in this activity and articulate both, as most of the teachers did and as she had done in previous topics; rather, she articulated a relationship between the two:

I thought this activity was a great analogy for the role and importance of observation in science. The more holes, the better the data. The bigger the holes the better the data. The
number of holes could be analogous to the quantity of observations or data – the more data scientists have, the better the inferences they can draw. The size of the holes could be an analogy to the quality of the data. E.g. finding a small fossil bone or an entire skeleton. Or observations with the naked eye compared to observations with a telescope. So this activity is great for observation. But it was also great in showing the role of inference – and that all our inferences depended on our previous knowledge (here of possible geometric shapes in our pictures). So empirical NOS is connected to inference and subjectivity and theory ladenness. (Sandy, J, 7)

A closer analysis of those teachers who expressed this linking or integration suggests that there were times when the generic NOS activities may have had a role in facilitating or mediating this integration. Frequently the teachers who integrated tenets referred to a NOS activity during their reflection, as in Holly’s response above.

**Increase in the number of responses when the tenet was not taught**

Shading of cells is used in Table 3.3 to show which NOS tenets were overtly taught during each topic or generic NOS activity. From this, it is possible to see the instances where NOS tenets that were not specifically addressed were nonetheless expressed by the teachers. Such instances would also suggest a positive shift in understanding. For example, during the geology unit Kit wrote of tentative NOS, which was not explicitly taught in the Geology sessions, linking it to empirical NOS and creative NOS.

Scientists use classification systems which are modified and changed over time as new observations are made. Science depends on these observations of the natural world, but imagination and creativity plays a part too just as we could classify the same set of rocks in our class in a huge variety of justifiable and defensible ways. (Kit, J, 10)

Table 3.3 shows that there was an overall increase in the number of times a tenet was expressed without being taught. In the opening Introductory Investigations topic, no teachers commented on NOS tenets not taught. Towards the end of the course, in the Continental Drift topic, 12 teachers reflected on empirically based NOS and 11 on inferential, imaginative, and creative NOS – none of which were specifically covered in this topic. Similarly, in the Young and Old activity, eight teachers reflected on tentative NOS and eight teachers on inferential imaginative and creative NOS, again not taught.

**Discussion**

In looking at the development of teachers’ understandings of NOS, several factors may have contributed to the positive shifts in understanding that were seen. Structured reflective writing, generic science-content-free NOS activities, and a course structure that allowed for both integrated and non-integrated approaches are considered to have contributed to these shifts.
Analysis of the data supports the role of structured reflection to effect shifts in conceptual understanding. The course was intentionally structured to encourage teachers to make journal entries at any time during the sessions, as well as during a set time at the end. It was found that very specific reflective prompts were effective in provoking reflection. The reflective journal writing was found to be more than a repository of data on their developing views. Analysis of the content of the entries suggests that it was a powerful tool to facilitate reflection, a means of enabling the teachers to consider and develop their own beliefs and understandings. Hewson, Beeth, and Thorley (1998) proposed four general guidelines for conceptual change. First, students and teachers’ ideas about the target topic (here of NOS) should be made an explicit part of classroom discourse, with structured opportunities to state and explain the nature, strengths, limitations, and consistency of their ideas. Second, discourse should be made explicitly metacognitive. Third, the status of ideas and concepts in terms of perspicuity, credibility, and fruitfulness should be explicitly discussed. Fourth, the justification for ideas and status decisions should be made an explicit component of the curriculum (Abd-El-Khalick & Akerson, 2004). Evidence of these four guidelines was apparent in the journal writing.

This research study used both integrated and non-integrated NOS instruction to address the demands of conceptual change that the developing of NOS understanding requires. It is reasonable to surmise that NOS teaching integrated within the science content topics can cause a degree of cognitive overload, which may in turn impede the development of NOS understanding. So for those teachers with little or no NOS understanding, the use of non-integrated generic NOS activities as pull-out activities could be considered to have reduced cognitive load and allowed the teachers the opportunity to encounter these new NOS concepts without needing to struggle with complex scientific concepts at the same time. When NOS activities were provided that allowed these NOS tenets to be taught devoid of any new science content to master, the data indicate that the teachers more readily understood the NOS tenets being taught.

The effectiveness of these generic activities can be understood in terms of a) their function as instructional analogies and b) their function in reducing cognitive load.

Instructional analogy has been described by Newby Ertmer and Stepich (1995) as “. . . an explicit, nonliteral comparison between two objects, or sets of objects, in different content domains, that describes their structural, functional, and/or causal similarities” (p. 5). Examples are saying a zero is like a bookmark; it has no value except as a placeholder, or Rutherford’s classic model of the atom based on an analogy with the solar system (see Genter & Gentner, 1983). It consists of a target case (about which new knowledge is desired), a base case (which is generally already understood to some extent), and a relation that maps elements from one case to the other; the analogy helps learners make connections between the pre-existing base knowledge and the new target. Other research suggests
analogies can facilitate abstraction from individual cases to general schemata, or help the learner generate new inferences about the target (May, Hammer, & Roy, 2006).

From a constructivist viewpoint, the analogy serves not just as a representative template used to compare and map base domain’s attributes to the target, but as a dynamic process that affects and is affected by changes in conceptual understanding. It is viewed as a tool that allows the learner to synthesise typically incomplete, fragmented knowledge into a model and apply, test, and revise that model on a continuous basis (Newby et al., 1995). In contrast to the simple analogy of a zero and a bookmark, a complex instructional analogy, such as the analogy of a city postal delivery system and the human circulatory system, can have many mapping points. It allows an individual to see multiple commonalities between seemingly disparate situations by looking past simple surface details to focus instead on underlying relational structure – how the components of the systems fit together and relate to one another. In so doing, analogies allow a person to make structurally sound inferences about new situations, and they provide the opportunity to productively draw on one’s wealth of existing knowledge (Day & Goldstone, 2011). Analogical reasoning is widely acknowledged as a powerful tool in human cognition. The educational implication is that when attempting to teach theoretical concepts, the presentation of complex instructional analogies can help, particularly when students are provoked to think deeply about relationships between the presented analogy and the theoretical concepts (May et al., 2005).

In this research, generic activities were used as simple analogies to teach ideas about NOS. For example, the ‘That’s Part of Life’ activity presents students with a cleverly written 600 word detailed description of doing the laundry, but does not use the words ‘doing the laundry’. The students are asked what the article is describing. Very few students make sense of the article until they are told that it is about doing the laundry – at which point the article makes sense to them. The analogy is then drawn to the existing theories and knowledge of the field that scientists hold, which allows them to make sense of data, and to the objectivity versus subjectivity of scientific endeavour.

The generic activities were also used to reduce cognitive load. Potentially the greatest constraint on learning in general, and therefore on transfer, is the severe cognitive restriction on the amount of information that can be processed at any one time. Research on working memory has provided a wealth of evidence that individuals are only capable of keeping a handful of units of information active simultaneously and are able to actively manipulate even fewer. Furthermore, this kind of knowledge is typically very short-lived (Day & Goldstone, 2012). This limited capacity also means that learners have fewer opportunities to elaborate on the new information by generating new inferences, making connections to existing knowledge, and developing more general schemas from the information (e.g., Sweller, 1994). Cognitive load theory (Sweller, van Merrienboer, & Paas, 1998) has looked to identify effective ways of managing processing demands during learning because of the
critical role that working memory constraints play in learning and transfer. Such research has shown that learning can benefit from manipulations such as removing irrelevant, distracting content, using cues to direct attention to relevant content, and allowing learners to pace their own training in order allow sufficient processing time (Day & Goldstone, 2012). In the current study the generic activities were used to remove the distracting content of science knowledge from the understanding of new NOS ideas. The teachers’ journal entries indicate that the teachers did indeed use these activities as cues and did pace their own learning of NOS ideas and of contextualisation of NOS ideas in a range of science contexts.

A few teachers were seen to abstract generalisations about NOS into a broader schema, which as a cognitive unit of the long-term memory (LTM) represents a higher level of organisation than a simple collection of lower-level components. In cognitive load theory, acquisition and automation of schemas in LTM are considered to be the most significant factors preventing cognitive overload in learning (Kalyuga, 2009). Moreover, the teachers enjoyed these generic activities and so it would be reasonable to conclude that these sorts of activities can play a very important role in addressing several affective issues in conceptual change. This clearly has important implications for the use of such activities when teaching NOS, at any level.

It was anticipated that the reflective journal writing would allow teachers the opportunity to reflect on the NOS tenet(s) in the generic NOS activity or the science content area they were reflecting on. It was also hoped that some would be able to make the links between the generic NOS activity being carried out and the content area in which it was embedded, as shown in Figure 3.1. As anticipated, the journal entries did suggest that the NOS activities facilitated establishment of connections between the tenets in the generic NOS activities and the tenets in the science content, and vice versa.

![Figure 3.1 Anticipated linking of NOS tenets in generic NOS activities and content areas](image)

Furthermore, the role of the generic NOS activities in scaffolding a deeper level of reflection can be seen in the reflective comments recorded by the teachers where, as the course progressed, teachers would frequently relate the NOS tenet being explicitly taught in a content area to a previous generic
NOS activity. For example, during the Geology unit Dana drew a connection between the internal structure of the earth and the prior ‘Hole Picture’ activity:

Scientists cannot directly see what is in the middle of the earth, just like we couldn’t pull out the coloured inserts, so development of ideas like the rock cycle must involve inference to a small or a large degree as well as observation. (Dana, J, 10)

Similarly, five teachers related NOS seen in the Continental Drift unit back to a generic NOS activity. Sandy, for example, linked tentative and empirical NOS to the ‘Aging President’ activity.

It can take years and years for a new scientific idea [like continental drift] to be accepted by the scientific community, and the general public. Reminds me of the aging president activity where it took me ages to change my ideas. It required the building up of a lot of observed evidence over a long period of time before the idea of continental drift became accepted. Existing paradigms can be very stubborn to shift. I saw too the role that technology can play in the advance of scientific ideas. Which drives which? Does technology drive science or science drive technology? (Sandy, J, 12)

This suggests that the generic NOS activities could play a mediating or linking role between seeing NOS tenets in the generic NOS activities and seeing NOS tenets within science content.

![Figure 3.2 Actual linking of NOS tenets in generic NOS activities and content areas](image)

The data showed that these generic activities also appeared to have scaffolded the teachers in recognising the inter-relatedness of the tenets, rather than seeing them as discrete entities. This ability to recognise NOS tenets as connected and integrated rather than being discrete is considered to be of particular significance and could be a key indicator of the depth of understanding of the teachers’ NOS understanding. As in Schwartz’s (2004) study, only a small minority of the participants showed an awareness of this linking and interrelatedness of NOS tenets and of the artificiality of separating NOS into distinct categories. The teachers’ reflective journaling indicates that the generic NOS activities may have scaffolded this integration.
**Integrated NOS teaching**

If students are to be successful and if schooling is to have a significant impact on their lives, it is essential that students regularly transfer what they learn (Engle, Lam, Meyer, & Nix, 2012). Transfer occurs when “learning to participate in an activity in one situation [i.e., learning context] . . . influence[s] (positively or negatively) one’s ability to participate in another activity in a different situation [i.e., transfer context]” (Greeno, Smith, & Moore, 1993, p. 100). For scientific literacy, students need to transfer their understanding of NOS into real-world contexts and personal action. This clearly requires much deeper learning than that afforded by learning a list of tenets and includes aspects “that are heavily value-laden, relate to gender and ethnic bias, address topics with a substantial moral-ethical dimension, and so on” (Hodson, 2009a, p. 71). To achieve a sophisticated epistemology, analogies as provided in the generic activities are useful but not sufficient. Therefore, NOS was also taught throughout as integrated with the science content being covered. Episodes from the history of science and consideration of contemporary socioscientific issues added to this integration. Integration was further strengthened by the strategic placement of the generic NOS activities – placing each within a topic to which it could be related. This allowed teachers who had sufficient conceptual understanding of NOS tenets in the activity, and of the science content, to contextualise NOS tenets for deeper conceptual change. So the generic NOS activities could be approached by the teachers as non-integrated pull-out activities (Lederman, 2007), or as a NOS activity closely related to the context (integrated). This structure provided a cognitive space within which the teachers could learn in a both a non-integrated or an integrated way (Clough, 2006).

**Concluding Thoughts**

To date, most NOS research studies have adopted either an integrated or non-integrated approach (Lederman, 2007). The design of this research provided the opportunity for both. Explicit integrated instruction occurred throughout each of the science content areas when course content was used overtly to draw attention to NOS. Designing the course to allow both integrated and non-integrated teaching and learning approaches, providing ample structured opportunities for reflection, and positioning the generic NOS activities so that they could be used as pull-out or integrated activities, are the factors considered to have facilitated the development of teachers’ understandings of NOS over the duration of the course.

This research has explored the role of structured reflection and the structuring of a course to combine integrated and nonintegrated approaches using generic NOS activities. With regard to the debate about whether NOS is better taught embedded within the science content or as a separate pull-out topic (Lederman, 2007), this research suggests that a course of learning should include both in order to cater for the level of conceptual understanding of all participants.
Chapter 4:
Realising the Potential of an Authentic Context to Understand the Characteristics of NOS and NOT: You, Me and UV

Introduction

Literacies in science and technology have been almost universally welcomed as a desirable goal for education (Hodson, 2008). The need for an understanding of the nature of science and the nature of technology (NOT) as a requirement of these literacies is well argued in the literature (Abd-El-Khalick & Lederman, 2000; Rennie, 1987; Shamos, 1995). However, research indicates that teachers do not usually hold informed understandings of NOS regardless of their academic ability, academic background, or teaching experience (Akerson et al., 2006; Davis & Smithey, 2009). Similar inadequacies have been identified when teachers are asked about their concepts of technology (Jones & Carr, 1992; Jones & Moreland, 2004; Rennie, 1987).

Hurd’s seminal view (1998) that the key issue in providing an educational experience appropriate for the 21st century, is that learning should be situated within a “lived curriculum” (p. 414) in a context where students are engaged in resolving real problems while understanding the practices of science and technology. It is acknowledged that providing a context is difficult, complex and problematic (Hodson, 2009b).

Situated learning theory (Lave & Wenger, 1991) provides a theoretical framework for understanding the importance of making connections between NOS and NOT and the context in which it occurs. Situated learning is based on the premise that developing understanding is ongoing, that knowledge must be learned in authentic contexts, and that learning requires increasing participation in a community of practice (Bell et al., 2011; Lave & Wenger, 1991). Consequently, a focus on authenticity could provide opportunities to learn about “ordinary practices of the culture” (Brown et al., 1989, p. 34) that occur when scientists and technologists are working within their community of practice.

Within situated learning theory, NOS and NOT understandings are best constructed within learning situations that are authentic (Jones & Baker, 2005; Rodrigues, 2006; Schwartz et al., 2004). What does authentic mean? It could be thought of as being pertinent to a student’s life, involving real issues, having a social impact, being informed by the activities of real scientists who are researching real issues and generating real data to solve real problems and involving real technologists who are using the resources of the world to develop appropriate interventions in real situations.
We contend that ‘realness’ does not equate to being simple. In fact, when issues are situated in the real world they are complex, contradictory, messy, uncertain, and puzzling. Such complexity often involves controversy, because within many science and technology contexts there are social, moral, ethical, cultural, economic, and aesthetic driving forces that influence outcomes.

The complexity of science and technology practices is made visible by Funtowicz and Ravetz (1993), when they characterise ‘Post-normal’ science with the complexity and uncertain outcomes that have the potential to be disastrous to society and the world. Songer, Lee, and McDonald (2003) also acknowledge the challenge and complexity of teaching within real-life contexts, but they assert that, however difficult it may be to provide such contexts, authentic activities are important in promoting inquiry for learners because they provide natural problem-solving contexts with high degrees of complexity. Authentic situations will demand opinions from learners and, when the situations have the capacity to affect them, students may be motivated to reach a justifiable position on the issue and choose to take appropriate action (Hodson, 2008, 2011).

However, it is a tall order to expect a primary teacher to present the real world of science and technology in their classrooms (Schwartz et al., 2004), especially as it is difficult to locate the resources that give such authenticity. It is equally challenging for teachers to identify NOS and NOT characteristics within such contexts. Indeed, we would argue that a preservice teacher’s ability to recognise NOS and NOT in any given context could be an indicator of their understanding. Consequently the following research question was posed: ‘What characteristics of NOS and NOT are identified, illustrated, and justified within an authentic context by preservice primary teachers?’

An opportunity to access the authentic world of science and technology has been developed as a virtual resource – the Science Learning Hub (www.sciencelearn.co.nz). This is a New Zealand government-funded initiative designed to increase student engagement in science, using a web-based portal. Its mandate is to make the research of New Zealand scientists more accessible and relevant to school students by providing connections between science knowledge, NOS, and what New Zealand scientists are doing in science.

The Science Learning Hub also covertly makes connections with the technology community as it identifies how scientists are using technology and how science research is informing technological development. In order to broaden this applied science view of NOT, another virtual resource, TechLink (www.techlink.org.nz) was used to access information from a strongly technological perspective. The ‘You, Me and UV’ context from the Science Learning Hub was used in this research project.

We assert that the Science Learning Hub has the potential to meet the four criteria for the attainment of context-based learning that Gilbert (2006) has developed from the work of Duranti and Goodwin (1992). These criteria are: setting of focal events, behavioural environments, specific language, and
extra-situational background knowledge. He argues that in order for the learner to be able to transfer their conceptual understanding into another context, these criteria need to be attended to (Gilbert, Bulte, & Pilot, 2011). These components will be interpreted in the following description of this context.

A focal event should motivate learning by having a direct relationship to some aspect of the learner’s life, and provide a framework for complex concept development that requires these concepts to be related. ‘You, Me and UV’ is personally relevant to New Zealanders as the incidence of melanoma is around four times higher than Canada, the US and the UK – two in three New Zealanders will develop a non-melanoma skin cancer during their lifetime and 1 in 17 will develop a melanoma cancer. The level of UV radiation that New Zealand receives is 40% higher during summer than at corresponding latitudes in the northern hemisphere (www.sciencelearn.org.nz). In this context, the focal event provides links between NOS characteristics related to issues such as measuring and monitoring UV, and the diagnosis of melanoma, and NOS characteristics related to issues such as skin protection and melanoma treatment.

The second criterion requires attention to the behavioural environment of the focal event. All the learning tasks were designed to promote discussion around NOS and NOT when discussing issues surrounding ultra violet radiation in New Zealand, such as the vitamin D production, the negative effects of UV skin damage, melanoma, wastewater treatment and skin protection.

To meet the third criterion for the attainment of context-based learning, learners need to develop the specific language that is required to appreciate the ‘essential nature’ of science and technology in terms of NOS and NOT, which was overtly taught. They also need the scientific and technological language of the context. In this UV context this included, for example, the language required for the interpretation of UV radiation graphs, or the analysis of the functionality of a sunscreen product.

In order to meet the fourth criterion, learners must be able to relate the focal event to relevant ‘extra-situational background knowledge’. This was the case with ‘You, Me and UV’ where the students were able to use their knowledge of NOS and NOT to identify illustrative examples from the context of ‘You, Me and UV’.

As discussed earlier, it is argued here that learning in context is best expressed within situated learning theory that Gilbert et al. (2011) asserts meets “these criteria for effective exploitation of the learning potential of context-based courses” (p. 821).

**Programme Content**

Identification of the Science Learning Hub and TechLink as resources gave this project legitimacy in the goal to provide an authentic, real, and contextualised approach to teach for an understanding of
It was hoped that this Science Learning Hub virtual resource would provide context-based learning and authenticity about the issues and problems that scientists and the wider community confront as they work towards developing scientific explanations of phenomena (Coll, France, & Taylor, 2005) and would facilitate technological outcomes that are critiqued as being ‘fit for purpose’ (de Vries, 2006). The scope of this resource included: New Zealand UV statistics; the dangers of UV exposure; the benefits of UV (such as vitamin D production); the uses of UV (such as water purification); and current research into UV-related issues such as melanoma, sunbeds, vitamin D production and children’s UV exposure. Issues such as the relationship between UV radiation and the incidence of melanoma, and the commercial promotions of sunbeds for tanning, provided social commentary on the focal event of UV radiation when taught within a behavioural environment, using specific language and building on background knowledge (Gilbert et al., 2011).

The programme was focused on developing preservice primary teachers’ NOS/ NOT understandings in the third year of a three-year Bachelor of Education degree. Tairab (2001) comments that teachers cannot teach what they do not understand, consequently it was necessary for these primary preservice teachers to be able to also recognise the differences between these two enterprises of science and technology as they have different purposes and a different epistemology. That is, the purpose of science is to understand and explain the natural world, whereas the purpose of technology is to extend people’s abilities to modify that world (Shamos, 1995).

Table 4.1 identifies the components of the relevant section of the course that provided these student teachers with knowledge about the essential nature of these curriculum areas. The course was structured with three sessions weekly: a 2-hour lecture (NOS and NOT) followed by two 2-hour practical workshop sessions (one NOS, one NOT). Decontextualised and contextualised teaching of NOS and NOT were used throughout, accompanied by guided practical activities, which emphasised the essential nature of these domains (Akerson & Donnelly, 2010). Added to this overt teaching, were frequent opportunities for the structured reflection that has been shown to develop teachers’ understanding of NOS (Heap, 2006; Morrison et al., 2009; Schwartz & Lederman, 2002).
In this research, the following characteristics of NOS were selected because they were identified from the literature as being accessible to students and have been commonly used in research studies (Lederman, 2007). It was also considered that they are clearly exemplified in the UV context. These are: scientific knowledge is tentative (i.e., durable but subject to change based on new evidence or new interpretations of existing evidence); science explanations are based on empirical data; there are a variety of ways of doing science; science is predictive, inferential and creative; science explanations are theory laden and subjective; and science is conducted in the public domain.

Also, these preservice teachers (i.e. students) were overtly taught particular characteristics of NOT. These characteristics were selected because they were identified during recent papers that informed the development of the revised ‘New Zealand Curriculum’ (Compton & France, 2007a, 2007b; Ministry of Education, 2007a). These are: technology enhances human capability; technology is outcome focused (material products and systems); technological outcomes are evaluated in terms of ‘fitness for purpose’; technological outcomes have a dual nature – functional and physical (de Vries, 2006), and technology is creative, innovative, and uses a wide range of information sources.

Epistemological differences between the domains were explored. For example, the empirical basis of science knowledge was demonstrated with a workshop where UV radiation data were measured with UV meters so that students had the experience of collecting, collating, analysing, and presenting UV measurements. This experience was supplemented with these students watching, via the online resource, scientists collecting, analysing, and interpreting UV radiation data. Using this virtual resource, the students also had access to a published paper that predicted a relationship between UV exposure, skin reddening (skin damage) and vitamin D production for different skin types (McKenzie,
Liley, & Björn, 2009). This paper showed how science data can be predictive, and illustrated that publication requires peer review.

This epistemological foundation of science knowledge was contrasted with technological knowledge that is validated through an epistemology of functionality. When exploring knowledge development, it was important to show how technology draws on other domains, and how this knowledge is operationalised for a purpose, e.g., sun protection. For example, during a technology workshop, UV measuring beads were covered with a range of sunscreens. The speed and intensity of the beads’ colour change provided evidence for the comparative efficacy of the sunscreens. This exercise provided students with an example of how science can inform technological knowledge. Students were made aware of the role of societal information informing technological knowledge when they explored sunscreens called ‘SugarBaby Suntan Sweeties’ designed specifically for young women. This provided students with an opportunity to discuss packaging and the marketing information that contributes to the normative function involved in critiquing technological knowledge.

Methods

Research strategy

This research was based on a premise that an understanding of NOS and NOT is central to scientific and technological literacies and, therefore, a preservice teachers’ ability to recognise NOS and NOT in any given context could be useful indicators of their literacy. An interpretivist research design (Sarantakos, 1998) was employed to answer the following research question, because this design provided space to acknowledge and explore individuals’ interpretation of NOS and NOT in this relevant context:

- What characteristics of NOS and NOT are identified, illustrated, and justified within an authentic context by preservice primary teachers?

Data answering this question were collected midway through the course when the students completed an assessed assignment task. This task required them to compile a table where they identified two characteristics of NOS and two of NOT, and to contextualise them with illustrative examples from the virtual resource ‘You, Me and UV’. They were also required to justify their choice of illustrative examples from the context.

Participants

Participants were a cohort of 46 third-year students enrolled in their final year as undergraduates in a Bachelor of Education (Primary) degree in a New Zealand university. As these students were in their third year of study, they had already completed a course in science (15 weeks in their second year of
study) and in technology (15 weeks in their third year of study). In order to determine this population’s existing knowledge base, students were asked to complete four open-ended statements about science and technology at the outset of the course (Tables 4.2 and 4.3).

**Table 4.2 Responses to open-ended statements to identify students’ existing ideas about science**

<table>
<thead>
<tr>
<th>Science is…</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploring/understanding the world</td>
<td>28</td>
</tr>
<tr>
<td>Domains of knowledge</td>
<td>28</td>
</tr>
<tr>
<td>Scientific process</td>
<td>20</td>
</tr>
<tr>
<td>A way of knowing/viewing the world</td>
<td>3</td>
</tr>
<tr>
<td>Technology focus</td>
<td>3</td>
</tr>
<tr>
<td>Not answered</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The purpose of science is…</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discover/explain/understand</td>
<td>28</td>
</tr>
<tr>
<td>Explore/investigate</td>
<td>15</td>
</tr>
<tr>
<td>Intervene/problem solve</td>
<td>14</td>
</tr>
<tr>
<td>Science education focus</td>
<td>8</td>
</tr>
<tr>
<td>Methodological focus</td>
<td>6</td>
</tr>
<tr>
<td>Not answered</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 4.3 Responses to open-ended statements to identify students’ existing ideas about technology**

<table>
<thead>
<tr>
<th>Technology is…</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit for purpose</td>
<td>16</td>
</tr>
<tr>
<td>Intervention/improvement/enhancing</td>
<td>16</td>
</tr>
<tr>
<td>Process</td>
<td>14</td>
</tr>
<tr>
<td>Product</td>
<td>12</td>
</tr>
<tr>
<td>Problem solving</td>
<td>7</td>
</tr>
<tr>
<td>Critical consumer</td>
<td>5</td>
</tr>
<tr>
<td>Education focus</td>
<td>5</td>
</tr>
<tr>
<td>All around</td>
<td>3</td>
</tr>
<tr>
<td>Forward focused</td>
<td>2</td>
</tr>
<tr>
<td>Applied science</td>
<td>1</td>
</tr>
<tr>
<td>Not answered</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The purpose of technology is…</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhance capability/benefit society</td>
<td>27</td>
</tr>
<tr>
<td>Product/process/fitness for purpose</td>
<td>10</td>
</tr>
<tr>
<td>Tech Ed focus(^8)</td>
<td>6</td>
</tr>
<tr>
<td>Intervention</td>
<td>5</td>
</tr>
<tr>
<td>Critical consumer</td>
<td>7</td>
</tr>
<tr>
<td>Future focused</td>
<td>3</td>
</tr>
<tr>
<td>Science related</td>
<td>2</td>
</tr>
<tr>
<td>Not answered</td>
<td>11</td>
</tr>
</tbody>
</table>

These data are presented here to provide a description of the participants. It shows that these students came with a broad, rather than a deep, understanding of science and technology, which is consistent with previous research (Compton & France, 2007c; Heap, 2007; Jarvis & Rennie, 1996; Lederman, 2007). For example, the majority of students described science as either a body of knowledge, or a general scientific process or a way of exploring/understanding of the world. Only a small number indicated a more contemporary understanding – that is, a way of knowing. Their responses indicated a more in-depth view of technology, possibly because they had just completed a technology paper in the previous semester. For example, they were aware of some contemporary views of technology, of it being seen to be a product outcome, a process, an intervention, and evaluated as being ‘fit for purpose’.

\(^8\) Such comments had a technology education focus – e.g. the student comment that ‘[t]he purpose of technology is to meet curriculum requirements’.

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This population held many different views about the purpose of science, with the most common response being to discover/explain/understand. Two other commonly expressed responses were those of exploring/investigating and to intervene/problem solve. This latter response could be interpreted as students giving science an applicatory focus. When completing the statement about the purpose of technology, most students gave a view of technology as enhancing capability/benefitting society. However, they lacked a sophisticated view of their role in determining the direction of technology as critical consumers.

These responses show that this population of preservice teachers brought some understanding of the domains of science and technology to the programme.

**Data collection and analysis**

Data from the open-ended statements were collected to provide a description of the participants and was analysed independently by three researchers, using open coding to identify themes that were then coalesced into broader categories. As these were open-ended statements, student responses could be coded into more than one category (Tables 4.2 & 4.3).

Data presented to specifically answer the research question were collected from the assignment given midway through the course. The two characteristics of NOS and NOT required from each student were frequency counted by three researchers independently and each collation was crosschecked. The illustrative examples were identified and similarly frequency counted and checked (Table 4.4 & 4.5).

In this assignment, students were also asked to justify each of their illustrative examples of their two NOS and two NOT characteristics. The following measures were given attention to ensure the reliability of the analysis – internal reliability of coding was ensured by discussion of the criteria used to ensure that the coders understood the criteria, and inter-coder reliability was ensured with further discussion between the coders of discrepant examples until consensus was reached (Bryman, 2008). Internal validity of this data analysis was provided in that a range of examples of each grouping was presented in their entirety to ensure some credibility of these claims (Cohen, Manion, & Morrison, 2011).
Table 4.4 Characteristics of NOS selected and illustrated by students

<table>
<thead>
<tr>
<th>Characteristic of NOS selected by student</th>
<th>n</th>
<th>Illustrative example</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative</td>
<td>40</td>
<td>Evolution of skin cancer diagnosis and treatment</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeline to show change in knowledge</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma Spread Pattern model – as a predictive tool</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma Spread Pattern model – based on a growing database</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring of ozone levels</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Controversy over vitamin D levels and UV exposure</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Revision of hypothesis of children’s UV exposure levels</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunscreen</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationship between UV and vitamin D (intensity and seasons)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UV to predict fluorescence in minerals</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sappey’s lines</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement of UV levels</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbed effects</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationship between ozone levels and climate change</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meaningless example given</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Empirical</td>
<td>37</td>
<td>Lymphoscintigraphy data</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma spread pattern model</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data of children’s UV exposure using dosimeters, skin types, time</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring of UV for time of day, seasons, and carrying heights</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cancer treatment</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Testing blood serum vit. D levels against UV intensity &amp; seasons</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NZ skin cancer statistics</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measuring fluorescence of rocks</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relationship between vitamin D levels and ethnicity</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement of ozone levels</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>View history/timeline</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Wide variety of ways of doing science</td>
<td>8</td>
<td>Dosimeters</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma spread pattern model</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lymphoscitigraphy data</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visible Human Project</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maurice Wilkins Centre</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Inferential and creative</td>
<td>5</td>
<td>Use of models to represent data</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma spread pattern model as a predictive tool</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunscreen related to SPF</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Socially &amp; culturally embedded</td>
<td>1</td>
<td>Skin Cancer Foundation research funding on children’s exposure</td>
<td>1</td>
</tr>
<tr>
<td>Theory laden &amp; subjective</td>
<td>1</td>
<td>Controversy between vitamin D and UV balance</td>
<td>1</td>
</tr>
<tr>
<td>Characteristic of NOT selected by student</td>
<td>n</td>
<td>Illustrative example</td>
<td>n</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>----</td>
<td>----------------------------------------------------------</td>
<td>----</td>
</tr>
<tr>
<td>Outcomes focused/material products and systems</td>
<td>32</td>
<td>Waste water treatment</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Melanoma Spread Pattern model</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunhats, shades, sunscreen, sunglasses</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waste water treatment</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ozone score data collector</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 different wastewater polishing models</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UV tubes and lighting</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin cancer diagnosis and treatment</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Creative, innovative &amp; uses wide range of sources</td>
<td>26</td>
<td>Three different wastewater polishing methods</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disinfecting wastewater</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3D computer model</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curing glues, resins and inks</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detecting fluorescent minerals &amp; disinfecting wastewater</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Invention and reinvention of sunscreen</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Children’s sunglasses</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring UV radiation / UV spectrometer</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dosimeter badge and children</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UV fluorescents for forensics and washing powder</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UV toilet blue lighting</td>
<td>1</td>
</tr>
<tr>
<td>Enhances human capability</td>
<td>16</td>
<td>Waste water treatment</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3D predictive model</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring ozone levels</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sun protection</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compact fluorescent lightbulbs</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meaningless example given</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weak example with classroom practice focus</td>
<td>1</td>
</tr>
<tr>
<td>Outcomes are evaluated regarding fitness for purpose</td>
<td>9</td>
<td>UV light to disinfect wastewater</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 D model</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skin lightening in Greek and Roman times</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compact fluorescent lightbulbs</td>
<td>1</td>
</tr>
<tr>
<td>Outcomes have a dual nature</td>
<td>8</td>
<td>Water polishing</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunbeds</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunscreen</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sunglasses</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meaningless example given</td>
<td>2</td>
</tr>
<tr>
<td>Modelling to test outcome’s practicality &amp; functionality</td>
<td>1</td>
<td>Disinfecting wastewater to (functional modelling prototyping)</td>
<td>1</td>
</tr>
</tbody>
</table>
Student’s justifications for their examples were analysed on a three-point scale:

- Level 1: Little or no justification given
- Level 2: Adequate justification given
- Level 3: Strong justification given using multiple lines of evidence or support.

Students at Level 1 either did not provide any justification, or the links between characteristic, example, and justification showed no understanding of the characteristics of NOS and NOT. Level 2 students identified a characteristic with an appropriate example, but while the justification did show a link to the identified characteristic, it lacked an explanation. Level 3 students showed clear links between the three components: that is, an explicitly identified characteristic, a carefully described example, and a justification which provided more than one rationale to support their choice. Table 4.6 in the findings section provides data for each level Tables 4.7 and 4.8 provide selected examples of justifications for further discussion in the findings section.

Findings

Two sets of data are presented to answer the research question from two different perspectives. Firstly, the collation of preservice teacher identification of NOS and NOT with examples, provided data to answer the first part of the research question that is “the characteristics and illustrations” (Tables 4.4 and 4.5).

Illustrating and identifying NOS and NOT characteristics

Tables 4.4 and 4.5 show a collation of the NOS and NOT characteristics selected by these students, and the examples they chose to illustrate these characteristics. The number of examples exceeds the number of students because each student selected one example for each of their two NOT and two NOS characteristics (four in total). Over 90% of this group were able to provide a relevant illustrative example of their selected characteristics.

Each of the six NOS characteristics identified in Table 4.4 had been taught. The two characteristics of NOS most commonly selected by the students were the tentative NOS and the empirical NOS with 89% and 80% of these preservice teachers, respectively, selecting these characteristics. This is consistent with the research literature that shows that these tenets appear to be more easily understood by learners (Abd-El-Khalick & Akerson, 2009). The characteristics of inferential/creative (11%), socially and culturally embedded (2%), and theory laden and subjective (2%) had a much lower representation. This virtual resource provided ample opportunities for students to choose characteristics other than tentative or empirical. Indeed, the same examples they selected to illustrate tentative or empirical NOS could have been selected to illustrate other characteristics of NOS.

Students who selected the characteristic ‘wide variety of ways of doing science’ showed an
appreciation that there is no single scientific method, however on the whole, their justifications were weak, as will be shown in the next section.

Each of the six NOT characteristics identified in Table 4.5 were taught. Student selection of an outcomes-focused characteristic (70%) reflects their understanding that the purpose of technology is the development of planned interventions. The use of an illustration showing that technology employs a wide range of disciplines in the production of such an outcome (57%) belies a commonly held misconception of technology as applied science (France, Compton, & Gilbert, 2011). Some responses (35%) showed these students’ ability to recognise the NOT enhancing capability, for example, a sun protection product that would allow longer sun exposure. The three characteristics with lower scores suggest that choosing examples that illustrate an understanding of the epistemological basis of technological knowledge (fitness for purpose and modelling) or being able to provide examples of the duality of technological outcomes, required a deeper understanding since potentially all characteristics could have been interpreted with equal frequency from the examples available on these virtual sites.

Tables 4.4 and 4.5 show that there were five weak examples where students identified a classroom-practice example, or in some cases, one that provided a meaningless example of NOS. Furthermore, there were four weak examples of NOT. Further analysis showed that these examples were provided by three students in total. Consequently, we assert that a majority of students were able to provide a valid illustrative example of their selected NOS or NOT tenet using the Science Learning Hub resource.

Levels of justification and exemplars

Secondly, in order to fully attend to the research question, justifications provided by the preservice teachers were analysed and collated into the three broad categories as shown in Table 4.6.

It is important to note that each student (n=46) provided a justification for each of the four characteristics (2NOS/2NOT). Table 4.6 shows that 82% of NOS justifications and 79% NOT justifications were adequate or strong.
Table 4.6 Strength of justification of illustrative example

<table>
<thead>
<tr>
<th>Justification for NOS</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Weak</td>
<td>17</td>
<td>18.5</td>
</tr>
<tr>
<td>Level 2: Adequate</td>
<td>29</td>
<td>31.5</td>
</tr>
<tr>
<td>Level 3: Strong</td>
<td>46</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Justification for NOT</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1: Weak</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>Level 2: Adequate</td>
<td>34</td>
<td>37</td>
</tr>
<tr>
<td>Level 3: Strong</td>
<td>39</td>
<td>42</td>
</tr>
</tbody>
</table>

Tables 4.7 and 4.8 present exemplars of preservice teacher justifications that have been analysed as strong, i.e., Level 3. In this figure, preservice teachers are identified by their allocated code (student number) to maintain their anonymity. We have decided to provide only high-level exemplars to illustrate the potential of this virtual resource, rather than show the range of justifications that these preservice teachers achieved, as such a discussion would become the focus of another research question.

Table 4.7 Exemplars showing an identification and contextualisation of NOS with justification

<table>
<thead>
<tr>
<th>Contextualisation using the Hub Resource</th>
<th>Justification for choice of context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific knowledge is tentative (Student 5)</td>
<td>Scientific knowledge and understandings are developed by people and while they are durable they are never absolute. Scientists are constantly coming up with new questions, interpretations and new opinions. Which are self-correcting. A timeline on a scientific context, such as this one on UV, clearly shows that the scientific knowledge is constantly being re-evaluated in the light of new evidence (influenced by social, cultural, ethical and values perspectives) and therefore changes over time. Students by studying and drawing their own timeline on UV will be able to see that the scientific knowledge on UV is tentative.</td>
</tr>
<tr>
<td>Science knowledge while durable is never absolute. The fact that science is tentative is clearly shown on the timeline of events related to UV (Science Learning Hub, 2008). For example the timeline shows that in 1804 there was the first description of melanoma as a disease. This scientific knowledge was durable until the 1960s when scientific examination of Peruvian Inca mummies (dated to be approximately 2,400 years old) revealed signs of melanoma which showed melanoma was not a new disease. However, it wasn’t until 1956 that scientific research showed that melanomas were directly associated with exposure to the sun.</td>
<td></td>
</tr>
<tr>
<td>Scientific knowledge is tentative (Student 2)</td>
<td></td>
</tr>
<tr>
<td>Hayley Reynolds (Auckland Bioengineering Institute) is developing a computerised 3D model of the body that will help doctors predict where a patient’s cancerous melanoma cells are more likely to spread, focusing on the lymph nodes. Hayley’s research aims to develop an efficient way of displaying which lymph nodes melanoma is most likely to have spread to, from any skin site in the body. These predictions are made through the use of a database of over 5000 previous patient’s data. The model has been put into a computer software programme that has a ‘built-in capability for doctors to record their patients’ data</td>
<td>Hayley’s 3D model for predicting the spread of melanoma cells through the lymphatic system helps show that science is tentative in that this model is a progressive step in the fight of cancerous melanoma. There is currently no reliable cure for melanoma once it has spread. The ways in which we can detect melanoma spread and early detection could drastically increase a person’s chance of recovery. Hayley has used the best possible data collected</td>
</tr>
</tbody>
</table>
straight away in 3D’. This means that the database can continue to expand (www.sciencelearn.org.nz).

Currently in order to make her model as accurate and up to date as possible. She has taken data that was previously only available in 2D and has represented it in 3D allowing doctors to base their treatment on the most recent scientific evidence and appropriate research. She has also built in the capability for doctors to record their future data findings in order to keep the model current, and also increase its database. Since the database is growing, it follows that the current findings are tentative and may change as the database enlarges.

Science explanations are empirically based (Student 18)

The children’s exposure to UV research project conducted in the summer of 2004–2005 is a scientific explanation on how much UV radiation New Zealand children were exposed to during a school day and during the weekend. 491 children and 27 schools were part of the study. This explanation is based on the observed and measurable data collected from electronic UV monitors (dosimeters) which logged each child’s UV exposure at eight-second intervals throughout the day. Journal recording also detailed activity, clothing, and sun protection as well as recording skin types.

This clearly shows that science explanations are based on empirical data. In this case the data can be used as an important source of information for developing health programmes and for future scientific research (Science Learning Hub, 2008).

Science is carried out in a wide variety of ways (Student 17)

I have chosen the ‘Maurice Wilkins Centre for Molecular Biodiscovery’ as my context to illustrate that there are a variety of ways of doing science. This context highlights several research groups and researchers working together through their own scientific interest (in a variety of ways), with a common goal of research excellence.

This context shows how several researchers (or groups) working together in a variety of ways is the most productive approach to science research. The Maurice Wilkins centre encourages entrepreneurial researchers to be flexible and innovative. Some examples of the diverse scientific disciplines used are: structural and molecular biology, proteomics, medicinal and synthetic chemistry, immunology, bioengineering and mathematical modelling. All of these disciplines use different approaches in different ways in order to find the best possible explanations. There is not one scientific method that all scientists follow in every discipline.
Table 4.8 Exemplars showing an identification and contextualisation of NOT with justification

<table>
<thead>
<tr>
<th>Contextualisation using the Hub Resource</th>
<th>Justification for choice of context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology is outcome focused (Student 43)</td>
<td>This is a prime example of an outcome-focused technological system. Hayley’s software allows doctors to predict where the melanoma has spread from and where it could spread to. The software aids doctors in treating and diagnosing melanomas. Her technological outcome was fit-for-purpose and allowed doctors to have a visual representation to support their explanation and presentation of treatment options to patients. ‘We have one of the highest rates of melanoma in the world, so I knew that if I came up with something that was useful in the field of melanoma, it could be locally useful here in our country.’ [Hayley’s quote]</td>
</tr>
<tr>
<td>Technology is creative, innovative and uses a wide range of sources of information (Student 30)</td>
<td>A wide range of information has been used to develop this wastewater system. Used empirical data about the effects of UVC light on wastewater, how it works and how well it works. They would need to find out the most efficient and effective levels of water to pass over the lights and develop ways to control the flow of water in different situations. Used the public/societal belief that waste water needs to be treated in some way before it is released back into the ocean, in the least harmful way to humans and marine life. This public opinion is backed up by knowledge of harmful effects untreated wastewater can do to the environment and humans. Used innovation and creativity to determine ways of keeping it running efficiently (e.g., the rubber rings and sections of it working at different times so light tube replacements can occur). Also thinking about how they can make it more beneficial and effective than previous disinfecting systems (e.g., not having to use harmful chemicals like chlorine).</td>
</tr>
<tr>
<td>Technological outcomes are evaluated in terms of ‘fitness for purpose’ (Student 18)</td>
<td>This context demonstrates how a technological outcome is evaluated in terms of fitness for purpose. Society in 900BC–500AD highly valued lighter skin. They developed a lead based whitening paint which gave skin a lighter appearance, responding to the ‘want’ or ‘need’ in society. However this technological outcome would not be deemed successful in today’s society, as the wants and needs have changed. It is no longer considered fashionable to have pale skin; therefore the technological outcome would be deemed as unsuccessful or useless in our society. Science findings have also found the lead based paint to cause death, madness and infertility; which would also impact on the successfullness in today’s society.</td>
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</table>

Ancient Greek and Roman women used a lead-based whitening paint to lighten their skin, as dark skin was undesirable in society.

Technology is a purposeful intervention in the world, which meets the needs and wants of society at any specific time, or place. The technological outcome needs to be both physical and functional within a specific society for it to be successful. If the same technological outcome was placed in a different social or historical context, it may be utterly useless or non-applicable.
Technology outcomes have a dual nature (student 10)

| Dual nature: | Physicality: The different materials that have gone into putting together a modern day sunbed have changed over the years to suit modern day salons. There are different shapes and sizes, colours and styles. The technological practice and knowledge combined have researched what objects, materials and management would go into getting a sunbed to do the right job. |
| Functionality: Sunbeds (and tanning booths and tanning beds) emit UV radiation and are used to produce a cosmetic tan. | Functionality: Does it do its job? ‘...to produce a cosmetic tan’. Sunbeds are meant to produce a tan to the consumer. That is its function and it does this regardless of whether it is good or bad for your skin. |
| Physicality: They use fluorescent lamps that have phosphor blends designed to emit UV in a spectrum somewhat similar to the sun. | |

The following discussion of these high-level exemplars provides evidence of the reasoning that the students used to illustrate, explain, and justify their selection of NOS and NOT characteristics. First the identification and contextualisation of NOS characteristics are discussed.

**Scientific knowledge is tentative**

Student 5 used the timeline from this resource as a historical perspective, to show that science knowledge, while durable, is never absolute. Student 5’s justification demonstrates an understanding that scientific knowledge will change in the light of new evidence. However, an indication that this understanding is deeper than simply an appreciation of the role of new evidence, was illustrated in the comment that science is a human enterprise and that scientific knowledge is influenced by social, cultural and value perspectives.

In contrast to this historical lens, Student 2 illustrates the tentative nature of scientific knowledge by looking at the predictive capacity and the ongoing development of Hayley’s 3D melanoma spread-pattern model. Student 2 argues that, because this model is based on an ever-growing database from the Sydney Melanoma Unit, the knowledge generated from the model will change in the future. Both students’ justifications demonstrate an understanding of the tentative nature of scientific knowledge.

**Scientific explanations are empirically based**

Student 18 uses a research project (described on the Hub site) that reported New Zealand children’s exposure to radiation in order to demonstrate an understanding of the empirical basis of scientific knowledge. This student provided evidence of an empirical focus by quantifying the number of children and schools involved, and by discussing both the instruments and procedures used to gather data. Student 18 showed an understanding that empirical data are measurable and observable by the senses; but understood that data are not always numerical because this student also discussed the use of photographs as empirical data. The justification also shows an understanding of the need for studies to be able to be replicated in order to establish reliability and validity.
**Science is carried out in a variety of ways**

Student 17 states that there is not a single scientific method and uses the Maurice Wilkins Centre for Molecular Biodiscovery as an illustrative context. This student provided examples to show the diversity of scientific disciplines and acknowledged that these disciplines will use different approaches when producing evidence for scientific explanations. However, Student 17’s justification does not show an understanding that within a single discipline and a single research focus, two scientists may approach the science questions differently and use different methodologies.

The following analysis is of students’ identification and justification of the NOT examples.

**Technology is outcomes focused**

Student 43’s example of a technological outcome is not run-of-the-mill as they chose a system rather than an object as the outcome. The computer model that Hayley has developed provides doctors with a computer-based system which allows them to predict the likely site to which melanoma has spread, and provides a visual representation for them to use in patient consultation. Student 43 is aware that all outcomes are judged according to their fitness for purpose. This justification demonstrates a sophisticated view of NOT in that the product was developed to best suit this group of users – patients and specialists.

**Technology is creative, innovative, and uses a wide range of sources of information**

Student 30 chose the Mangere Waste Water system to illustrate that technologists access many sources of information when developing interventions. For example, in this justification the student acknowledges a scientific input, a social input, and the creativity and innovation involved when technologists use this information to develop and/or adapt such water-treatment systems. This student acknowledges the need for an ongoing innovation in order to ensure that a technological outcome continues to be fit for its purpose.

**Technological outcomes are evaluated in terms of fitness for purpose**

Student 23 has located her example in a historical frame by using an example from the timeline. This student demonstrated that an outcome cannot be evaluated just in terms of whether it does the job, but that there is a normative element of acceptability by the community within an evaluation. This student has indicated that an outcome must be evaluated within the social context in which it has been developed. Student 23 reflects that this lead-based, skin-whitening paste would not have been acceptable in modern society.
Technology outcomes have a dual nature

Student 10’s example provides evidence of an understanding of the dual nature of a technological outcome. This student analyses sunbeds, both in terms of their physical nature, by looking into the change of materials and design to suit modern preferences; and the functionality in terms of the production of a cosmetic tan for the user. Student 10 shows some awareness of the social impact of this outcome in that they recognise the negative effects of sunbed tanning.

It should be reiterated that the examples provided in Tables 4.7 and 4.8 are given as exemplars of preservice teacher justifications that have been analysed as strong – Level 3. Not all students were able to use this resource in this way. For example, Student 8 selected ‘tentative’ as the NOS characteristic and ‘measuring vitamin D levels’ as the illustrative context. However, the justification for selecting this illustration was that, ‘Scientists are never sure about their results so they are tentative’. The justification was too brief to ascertain the depth of level of justification. Similarly, Student 27 used ‘disinfecting wastewater’ as the illustrative context for technology being outcomes focused. Their justification was analysed as Level 1 as it had purely a teaching practice focus, ‘Teachers could visit a wastewater treatment plant so that their students could see this technological outcome first hand’.

Discussion and Conclusion

The research question asked: What characteristics of NOS and NOT are identified, illustrated, and justified within an authentic context by the preservice primary teacher.

These preservice teachers were able to identify six characteristics of NOS and provide illustrative examples. These were that scientific knowledge is: tentative; based on empirical data; inferential and creative; socially and culturally embedded; theory laden and subjective; and are carried out in a wide variety of ways. The six characteristics of NOT identified and illustrated by these preservice teachers were that technology: is creative and innovative; is outcomes focused; enhances human capability; has outcomes with a dual nature; is evaluated according to fitness for purpose; and uses modelling to test its practicality and functionality. Over 90% of the students were able to select and provide a valid context from the Hub to illustrate their selected NOS or NOT characteristic.

The development of an understanding of NOS and NOT must move beyond the identification of characteristics, which can be reduced to rote repetition of slogans (Clough & Olson, 2008). The richness of this authentic virtual context allowed these preservice teachers to identify a wide range of illustrative examples from the science of water treatment, melanoma research, and radiation measurement to the technological outcomes of sunbeds, sunscreen, and wastewater polishing methods. We argue that an ability to illustrate a characteristic shows a deeper level of understanding than just being able to state the characteristic. Furthermore, we argue that being able to justify an illustration
requires an even deeper level of understanding. The majority of these preservice teachers were able to provide an adequate or strong justification of their illustrative example.

Gilbert et al. (2011) propose that in order for the learner to be able to transfer their conceptual understanding into another context, there are four criteria that need attention. The ‘You, Me and UV’ focal event contained the complexity of concepts that allowed these preservice teachers to appreciate the specific language and extra situational background knowledge that was needed to participate in this behavioural environment that involved scientists, technological outcome evaluations, and societal influences.

Our research aim set an even more difficult task than the development of conceptual understandings, because we wanted these preservice teachers to understand not only the science and technology involved in this context but the epistemology of both of these domains. We were aware of Hodson’s (2009a) view that teaching in context is difficult, complex, and problematic. This difficulty was compounded for us with the necessity of accessing science and technology communities where the characteristics of NOS and NOT could be identified and contextualised.

Is it possible for primary preservice teachers to become aware of the characteristics of NOS and NOT in this messy enterprise of science and technology? We would argue that this research project has shown that it is possible for preservice primary teachers to recognise the philosophical basis of these knowledge developing domains if they are exposed to overt teaching of these characteristics within such a rich focal event.

However, it is not just an exposure to these examples in this focal event that deepened their learning. Instead, we contend that the data collection strategy that required students to identify NOS and NOT with illustrative examples and specific justifications enabled them to reflect on their developing understandings. This reflective activity provided the framework required to facilitate conceptual change (Morrison et al., 2009; Schwartz & Lederman, 2002).

Consequently we assert that authentic contexts coupled with an appropriate reflective framework and overt teaching of NOS and NOT have the potential to develop understandings so that learners are able to recognise some of the ways in which scientists and technologists practise their profession (with all of its messiness and lack of focus).

**The possibilities**

This Hub resource shows how the virtual world provides the opportunity to access science and technology communities, the contexts in which science and technology is practised. Often these situations are ill-defined and, because students were aware of the epistemological differences between the domains of science and technology, they were able to identify the relationship between science
and technology. This research supports Compton’s (2004) assertion that student learning in science and technology can be enhanced through their mutual study.

By understanding the differences and relationship between these two domains, students in educational settings will gain an appreciation of the nature of each at a more philosophical level. This is important to the development of both a scientific and technological literacy that will allow for informed citizenship (Compton, 2004).

In particular, these student teachers were able to demonstrate an understanding that science and technology are different yet symbiotic. “Technology is much more than applied science and science is quite different from applied technology” (AAAS, 1989b, p. 26). As well as being able to distinguish between these domains they were equipped with strategies to critically appraise the quality of the empirical data and/or appreciate the breadth of knowledge bases that could be tapped when technological outcomes were developed and, indeed, their impact on society when they were implemented.

However, a limitation of this study is that the preservice teachers were only asked to identify, illustrate, and justify NOS and NOT within the one context of ‘You, Me and UV’. It would be useful to research if these preservice teachers were then able to transfer this deeper understanding of NOS and NOT to being able to identify NOS and NOT in another context.
Chapter 5:
Riding the Wave: Using Web 2.0 Technology to Develop NOS Understanding among Preservice Teachers

Introduction

Understanding of the nature of science as a crucial educational component of scientific literacy is well argued in literature and is clearly reflected globally in science education documents and reform initiatives, including the New Zealand curriculum document (Ministry of Education, 2007a). It is of critical importance to research effective ways for preservice teachers to develop their own understanding of NOS in order to teach it in a transformed school science programme which engages and retains students’ interest in science.

Students enrolled in the one-year programme of the Graduate Diploma in Teaching (Primary) at the University of Auckland are required to take a semester-long science methods course. A key emphasis of this course is developing an understanding of NOS. Almost without exception, students enter this course with very limited understanding of NOS. The conceptual change required is therefore significant, and within a short time frame. This study examined the effectiveness of using a Web 2.0 application to manage this tension and provide multiple opportunities for the learning required to effect conceptual change. It reports on the effectiveness of Google Wave as a tool to support preservice teachers’ development of NOS concepts.

Data were collected using: open-ended questionnaires; selected items from the Views on Science-Technology-Society (VOSTS) questionnaire (Aikenhead & Ryan, 1992); the preservice teachers’ regular reflections in the form of ‘get out of class cards’; submissions on Google Wave; and assignment and test data. Analysis of the data obtained showed a considerable shift in students’ expressed NOS views and provokes consideration of how new Web 2.0 technology could be applied to the learning spaces of universities and schools.

Background, Framework, and Purpose

The knowledge society has priorities for learning which are so different from traditional schooling that it could be said to constitute a new paradigm (Gilbert, 2010). There is a pressing educational agenda for science educators to renegotiate the culture of school science to meet the 21st century needs of future citizens and scientists (Fensham & Harlen, 2010; Hodson, 2003, 2011). From a social perspective, one objective of current science teaching is to produce an informed public – scientifically literate individuals who can make decisions and engage in dialogue about socioscientific issues.
outside formal education settings (Guerra-Ramos, Ryder, & Leach, 2010). Hodson proposes that universal critical scientific literacy, that is, learning about science, “is one of the educational imperatives” to prepare students to manage life in our changing world (Hodson, 2008, p. 38). An understanding of NOS as a crucial educational component of this scientific literacy is widely argued in literature (e.g., Lederman, 2007) and is clearly reflected globally in shifts in science education documents and reform initiatives (e.g., Dagher & BouJaoude, 2005; Hodson, 2009a). Current science education curricula and reform efforts reflect a shift away from the learning of science content alone towards a curriculum also focused on learning about the nature of science. The New Zealand Curriculum (2007) recognises this imperative in describing NOS as the “overarching unifying strand” and states that “the core strand, Nature of Science, is required learning for all students up to year 10” (Ministry of Education, 2007a, pp. 28–29).

However, research studies to date have shown that teachers generally do not hold informed understandings of NOS regardless of their academic ability, academic background, or teaching experience (e.g., Akerson et al., 2006). Teachers’ views of NOS are critically important given that to convey appropriate NOS conceptions to students, teachers must hold views of NOS that are sufficiently extensive and critical to be able to determine what NOS to teach at each level. It follows, then, that preservice teacher education institutions must take their role seriously in adequately preparing preservice teachers to teach NOS. Improving NOS understandings is complex, and requires an approach that addresses conceptual change (Clough, 2006). The extensive literature on conceptual change indicates the key roles of reflection and metacognition in developing NOS understandings, and suggests that explicit, reflective instruction is necessary to address any misconceptions held by students.

A substantial body of research indicates that explicit NOS instruction can be effective in developing the type of understandings prescribed in science education reform documents (e.g., Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000a; Akerson & Hanuscin, 2007; Khishfe, 2008; Morrison et al., 2009; Scharmann, Smith, James, & Jensen, 2005). Explicit does not mean didactic transmission. Rather, an explicit approach proposes that NOS needs to be overtly addressed as an instructional outcome of science lessons, activities, and discussions and must be “planned for instead of being anticipated as a side effect” (Akindehin, 1988, p. 73). Advocates of an implicit approach suggest that an understanding of NOS can be achieved tacitly through participating in science inquiry activities and process skills instruction that are consistent with the construct. However, empirical research does not generally support this claim (e.g., Crawford, Bell, Blair, & Lederman, 1999; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002).

A reflective approach to NOS instruction is also considered necessary. Schwartz (2004), for example, has proposed that reflection on NOS may be the “critical pedagogical component” required for the
successful teaching of NOS (p. 8). Reflective approaches provide structured and guided opportunities for learners to examine their own views and, in this case, identify the discrepancies between their NOS conceptions and those presented. Learners should be given ample opportunities to experience, discuss, and reflect on various aspects of NOS in order to facilitate conceptual change towards a more informed understanding. Therefore, it is needful that preservice teacher educators provide strategies and space for teachers to elicit and identify their personal theories about scientific enterprise, to explore these by examining their rationale, by problematising, and by looking for alternative ideas. Consequently, the research design for this study incorporated an explicit reflective approach, and consistently provided opportunities for repeated critical reflective thinking, and reflective writing, when learning about NOS.

In order to facilitate this reflection effectively, one widely used strategy was employed and one new strategy was trialled. The widely used strategy was the incorporation of generic science-content-free activities (henceforth ‘generic activities’), such as those developed by Lederman and Abd-El-Khalick (1998). These activities have been purposefully designed to illustrate aspects of NOS, but they contain no science content. They are generic in nature, rather than content specific, as it has been suggested that teaching NOS and science content separately might distribute the cognitive load for students (Clough, 1997). In this study, these generic activities were strategically placed throughout the course in order to develop some basic understandings about NOS and were followed by whole class and group NOS related discussion concerning the presented ideas.

The new strategy used was to assist reflection using Web 2.0 technology. The term Web 2.0 is used to describe a second generation form of the World Wide Web that emphasises collaboration and sharing of knowledge and content among users (McLoughlin & Lee, 2008). Social software has emerged as a major component of the Web 2.0 movement’s use of networked computing to connect people in order to boost their knowledge and their ability to learn. Web 2.0 allows customisation, personalisation, and rich opportunities for networking and collaboration – all of which offer considerable potential for addressing the needs of today’s diverse student body (Bryant & Wilcox, 2006).

The Web 2.0 platform trialled in this study was Google Wave – loaded onto a class set of laptops for student use and used in all course lectures. Google Wave is a real-time online web application and computing platform combining personal communication, instant messaging, a wiki, and social networking.

The application meets the sociocognitive considerations of collaboration, learning how to learn and the idea improvement considered essential for knowledge building (van Aalst, 2009). Knowledge building emphasises the goal of collective knowledge advancement within a community (Scardamalia & Bereiter, 2003a). The collaboration required is more than the sharing of ideas. Rather, students have
access to the ideas of other students and attempt to consolidate these in order to improve their own understanding and to build knowledge – in this instance new collective and individual understanding of NOS, of the community of which they are a part (van Aalst, 2006). The aim was for students to treat ideas as objects of inquiry that can be improved by debate, scrutiny, investigation, and discussion rather than expert knowledge to be blindly accepted (Allchin, 2011).

It was intended that, together, these two strategies (generic activities and Google Wave), would provide repeated, ongoing opportunities for scaffolded reflection and create the ‘aha moments’ of conceptual change. Lave and Wenger’s (1991) perspective on situated learning theory provides a theoretical framework for understanding these connections between NOS instruction, context, and Web 2.0 environment since one of the major assertions of situated learning includes the understanding that a concept is a result of ongoing construction, and that learning is a process of increasing participation in a community of practice (Lave & Wenger, 1991; Orgill, 2007).

The research aim was to identify existing NOS understandings and to map shifts in these understandings over the duration of a science course that provided structured and repeated opportunities for reflection by using Google Wave in addition to generic science-content-free NOS activities and explicit teaching of NOS. The research questions were:

- What are the initial understandings of NOS held by these preservice teachers?
- What aspects of NOS show a shift in understanding over the duration of the course?
- What are the strengths and limitations of using Google Wave to structure reflection, facilitate, and record shifts in NOS understanding?

While the overall study involved each of these questions, the primary focus of this chapter is research question 3. Elements of findings and discussions drawn from data collected for research questions 1 and 2 will be presented (where relevant) to further inform the evaluation of Google Wave.

*Framing NOS for this research study*

In order to examine NOS understanding and shifts in understanding it is necessary to briefly discuss some of the aspects of NOS which were communicated in this course. Despite the longevity of NOS research, what NOS should be taught remains a contested domain. Indeed “no one agreed-on NOS exists” (Alters, 1997b, p. 48). Some scholars hold the view that different and even conflicting views of NOS should be presented to students so as to give a more realistic picture of science (Alters 1997b; Nott & Wellington, 1993; Wan, Wong, & Zhan, 2013) while others contend that despite a lack of a universal definition, there exists considerable consensus regarding NOS content to be taught. Within this latter view Lederman and colleagues summarise the following ‘agreed upon tenets’ as being the most appropriate for science education: scientific knowledge is tentative; empirical; subjective and
theory-laden; partly the product of human inference, imagination, and creativity; and social and culturally embedded (Lederman et al., 2002).

These five tenets, among others, such as the difference between observation and inference and between theories and laws, have been used in many previous studies of NOS (e.g., Abd-El-Khalick & Lederman, 2000a; Bell et al., 2000; Matkins et al., 2002). They were accepted in this present study as a pragmatic starting place for student understanding and for data analysis. It was stressed throughout the course that an adequate understanding of NOS for teachers is much more complex than a merely superficial knowledge of the tenets above. These are merely some characteristics of science that teachers need to be able to contextualise and illustrate in their own classroom practice. If NOS instruction stops at recall and comprehension of tenets, it remains superficial; in terms of Bloom’s taxonomy it would be at the first two levels (remember and understand). It was anticipated that the use of Google Wave would facilitate levels 3–5 (apply, analyse and evaluate) and meet Allchin’s challenge of setting sights for science education “well beyond a handful of simple tenets” (Allchin, 2011, p. 528).

Methodology and Research Design

The research used a case study approach (Huberman & Miles, 2002) and was embedded in critical social science methodology as underpinning both critical social science and the educational goal of scientific literacy and NOS, is the emphasis on transformation, emancipation, and change; helping individuals to “change conditions and build a better world for themselves” (Neuman, 2003, p. 81). This is predicated on the view that individuals who understand NOS are enabled to ask fundamental questions, analyse, and challenge accepted norms, make judgements and solve problems in scientifically related issues. Such individuals are empowered to function within and change society (Keske, 2002). This project was seen as having this potentially transformative, emancipatory function for the participating students, and in turn for their own students, and also to initiate change in the lecturer’s practice. The research participants were a cohort of preservice primary school teachers – students enrolled in the Graduate Diploma (Primary) University degree programme (n=42). All the students had an undergraduate degree but, for most students, this was not in a science discipline.

Throughout each session, the students were asked to identify specific aspects of NOS which were taught explicitly by the lecturer, or were covered implicitly in the course content. When students observed such NOS teaching, they entered a brief comment using their laptops into Google Wave, an online application that aimed to transform group communication with real-time entries. The interface was intuitive and its refresh-rate near instant, meaning that other students and the lecturer were then able to read the comments as the session was progressing, and to add their own responses, if appropriate. A Wave, in this service, is a space where participants can reply in a threaded manner to
one another’s comments with text or multimedia, with their contributions appearing on each other’s screens (and a large projected screen behind the lecturer) in real-time. Students were also encouraged to add to these comments in their own time after the sessions. They could also upload web images and video clips (e.g., from YouTube) alongside relevant comments which they or another student had already entered on the Wave.

Data Collection and Analysis

Students’ developing understandings of NOS were monitored through the following data:

- An initial questionnaire consisting of four open-ended statements was used to map the students’ initial understanding of NOS and was repeated at the end of the course. The students were asked to complete the following statements: Science is…; Ideas come from…; Experiments are…; The skills required by scientists are…

- Students were given ‘Get out of class’ reflective cards, with NOS as the focus, and asked to briefly respond to the questions printed on the card. The questions were loosely based on Brookfield’s (1995) critical incident questionnaire: When thinking about the nature of science teaching in today’s lecture, What is one thing you learnt?; When were you most engaged?; When were you most distanced?; What was most puzzling or confusing?

- All contributions made by the students during each lecture remained as a growing repository and could be analysed. Contributions made by the students through Google Wave after the lectures and during their own study time were also tracked and analysed.

- As part of one assessment task, the students planned a teaching unit which incorporated teaching on NOS.9

- Test questions at the end of the course required students to identify aspects of NOS that could be covered in a variety of science-teaching topics.

- All students completed the standard University Course Evaluation and a written evaluation of Google Wave.

The framework of the five tenets previously described for this study was used to analyse each of the data sources, allowing the researcher to achieve consistency throughout data coding by providing an existing theoretical framework, which indicates to the researcher “where to look for facts and how to interpret them once they are uncovered” (Neuman, 2003, p. 86). Once the data were analysed and coded to these tenets, each set of data was reviewed and frequency counts were made for the codes to indicate the tenets expressed by each of the participants. All data were also analysed by a research assistant. Internal reliability of coding was ensured by comparison of codes and discussion of the criteria used to ensure that the coders understood the criteria. Inter-coder reliability was ensured with

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9 This was required to be explicit teaching of NOS incorporated within the context of the topic being taught.
Further discussion between the coders of discrepant examples until consensus was reached (Bryman, 2008).

Findings

In order to inform the evaluation of Google Wave, a snapshot of data concerning the students’ initial NOS understanding and their shifts in understanding (a small section of data addressing research questions 1 and 2) is discussed briefly. Table 5.1 shows the results of the analysis, using a NOS framework, of the initial and final questionnaire. Counts were made only when a student’s response clearly and unambiguously expressed a NOS tenet. The table presents the tenets in descending order with the most commonly expressed at the top. It shows final open-ended question responses (in black) and responses from the initial open-ended questions (in grey).

Table 5.1 NOS understandings indicated in initial and final open-ended question responses

<table>
<thead>
<tr>
<th>NOS tenet</th>
<th>Initial</th>
<th></th>
<th>Final</th>
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<tbody>
<tr>
<td></td>
<td>Number of participants who clearly indicated NOS tenet</td>
<td>Percentage of participants who clearly indicated NOS tenet</td>
<td>Number of participants who clearly indicated NOS tenet</td>
<td>Percentage of participants who clearly indicated NOS tenet</td>
</tr>
<tr>
<td></td>
<td>(n=42)</td>
<td>%</td>
<td>(n=42)</td>
<td>%</td>
</tr>
<tr>
<td>Science is empirically based</td>
<td>16</td>
<td>43</td>
<td>40</td>
<td>95</td>
</tr>
<tr>
<td>Scientific knowledge is tentative</td>
<td>13</td>
<td>31</td>
<td>40</td>
<td>95</td>
</tr>
<tr>
<td>Inferential/imaginative/creative</td>
<td>6</td>
<td>14</td>
<td>36</td>
<td>86</td>
</tr>
<tr>
<td>Subjective and theory laden</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>76</td>
</tr>
<tr>
<td>Socially and culturally embedded</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>71</td>
</tr>
</tbody>
</table>

Table 5.1, while only a snapshot, suggests that significantly more students articulated tenets of the selected aspects of NOS at the conclusion of the course. In the initial questionnaire, fewer than half the students expressed an understanding of any individual tenet of the analysis framework used. At the conclusion of the course, each of the tenets was clearly expressed by more than 70% of the students, with 95% showing in their written responses an understanding that science is empirically based and that scientific knowledge, though durable, is tentative.

Table 5.2 further substantiates the shift in students’ understanding. All entries in the students’ regular ‘get out of class’ reflective cards and submissions on Google Wave were also coded for the articulation of NOS tenets. Table 5.2 shows the quantitative results of this analysis. This table shows the number of students who expressed a NOS tenet in their written Google Wave posts or reflective comments in each topic or NOS activity. Columns A and B are a chronological overview of the course. Column C shows the number of students who clearly expressed an understanding of at least one NOS tenet in their posts or reflections and Columns D–H identify which of the selected NOS...
tenets were explicitly articulated. Multiple references to the same NOS tenet by each student scores as only one, since the analysis shows how many students articulated each tenet – not how many times the tenet was expressed. The total number of comments in each topic or generic activity commonly exceeds the number of students who expressed NOS tenet/s as the students may have articulated more than one tenet. The shading of the cells (columns D–H) indicates tenets explicitly and overtly covered during the topic or activity. Within any of the topics covered, it would have been possible to see each of the selected NOS tenets, but those shaded were specifically addressed.

Table 5.2 Students’ written responses throughout course

<table>
<thead>
<tr>
<th>Column A</th>
<th>Column B</th>
<th>Col. C</th>
<th>Columns D–H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topics</td>
<td>Generic NOS activities</td>
<td>NOS tenet expressed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science-content-free explicit NOS activities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of teachers who expressed NOS tenet(s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tentative</td>
<td>Empirical</td>
<td>Subjective/theory laden</td>
</tr>
<tr>
<td>Animals</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Plants</td>
<td>5</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Electricity</td>
<td>9</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Tricky Tracks</td>
<td>38</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>Dogs and Turnips</td>
<td>38</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Physical &amp; Chemical Properties</td>
<td>32</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>That’s Part of Life</td>
<td>27</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>The Whole Picture</td>
<td>29</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Sound</td>
<td>31</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Geology</td>
<td>35</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>The Hole Picture</td>
<td>39</td>
<td>34</td>
<td>30</td>
</tr>
<tr>
<td>Young &amp; Old</td>
<td>36</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Astronomy</td>
<td>40</td>
<td>37</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 5.2 shows the increase in expression of NOS tenets over the duration of the course, suggesting a developing understanding of NOS and/or a developing ability to articulate that understanding. The initial topic, Animals, saw four NOS comments made by three students. Astronomy saw 151 comments made by 40 students. All tenets of NOS showed a shift in understanding. Analysis of all written responses also showed an increased complexity in the students’ expression of NOS and also in their postings of tenets during a topic or activity in which it was not specifically taught by the lecturer.

The data presented in Tables 5.1 and 5.2 contribute to answering research question 3, the focus of this paper, in that these data show: a) shifts in understanding occurred; and b) that posts on Google Wave
were able to be analysed to record these shifts.

Providing further data, the students were asked at the completion of the course to evaluate the use of Google Wave by providing written responses to questions such as:

- In what ways did Google Wave enhance or hinder your learning and understanding?
- Can you suggest improvements in using this type of technology as a means to engage you in the sessions?
- How would you use this type of technology in your teaching?

The students’ responses were analysed and coded for emerging themes. These results are given in Table 5.3.

**Table 5.3 Comments expressed on use of Google Wave in end-of-course evaluation**

<table>
<thead>
<tr>
<th>Comment expressed</th>
<th>No. of students who indicated this theme (n=42)</th>
<th>% of students who indicated this theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOS is interesting/not boring</td>
<td>34</td>
<td>81</td>
</tr>
<tr>
<td>Encouraged discussion/stimulated interest</td>
<td>32</td>
<td>76</td>
</tr>
<tr>
<td>Fostered explicit teaching and learning of NOS</td>
<td>31</td>
<td>74</td>
</tr>
<tr>
<td>Allowed us to share ideas and understanding</td>
<td>28</td>
<td>66</td>
</tr>
<tr>
<td>Allowed deeper reflection</td>
<td>28</td>
<td>66</td>
</tr>
<tr>
<td>Made you think about learning and understanding</td>
<td>27</td>
<td>64</td>
</tr>
<tr>
<td>Provided for immediate reflection</td>
<td>26</td>
<td>62</td>
</tr>
<tr>
<td>Allowed me to see the thinking of other students</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>Allowed access outside of class to deepen understanding</td>
<td>21</td>
<td>50</td>
</tr>
<tr>
<td>Can ask questions without disrupting the flow of the lesson</td>
<td>18</td>
<td>43</td>
</tr>
<tr>
<td>Allowed me to see NOS in action</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>Saw how much understanding I lacked despite my academic background</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>Was not invasive</td>
<td>18</td>
<td>43</td>
</tr>
<tr>
<td>Provided learning on multiple levels</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Allowed for learning at different rates</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Could be accessed by those who ‘were ready’, and be ignored by others</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Created a learning community</td>
<td>15</td>
<td>36</td>
</tr>
<tr>
<td>Would like to use this or other blog-type technology in my own teaching</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td>Was difficult to both listen and record on Google Wave</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Was a hindrance to learning</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Was a distraction</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 5.3 shows that more than 70% of the students evaluated Google Wave as having fostered explicit teaching and learning of NOS, encouraged discussion, and stimulated interest. Fifty to 70% of the students commented directly on the reflection facilitated by the use of Google Wave with themes such as: it allowed us to share ideas and understanding; allowed deeper reflection; made you think about learning and understanding; provided for immediate reflection; allowed me to see the thoughts of others; and allowed access outside of class to deepen understanding. Three students, however, considered the Google Wave experience to be a hindrance to learning, with one of these three commenting that it was a distraction.

Discussion

Using web-enabled devices and a host computer coupled to a data projector allowed students to respond in real-time and comments/posts could be seen immediately and easily. This provided evidence of participation by most of the class. Students could record contributions, or responses to others’ contributions instantaneously. Sharing comments was unobtrusive.

The Wave postings had implications for both the lecturer and the students as part of the learning community. For the students as learners, this Web 2.0 application provided: a structure to facilitate repeated and persistent opportunities for reflection, and structured and guided opportunities for learners to examine their own views and identify the discrepancies between their NOS conceptions and those presented. It addressed Schwartz’s (2004) assertion of reflection on NOS as being the critical pedagogical component required for the successful teaching of NOS. Google Wave allowed the students to ‘share ideas and understanding’ (66%) and ‘see the thoughts of others’ (60%) (see Table 5.3). Van Aalst (2009) asserts that it is this access to the ideas of other students, and attempts to consolidate these ideas in order to improve their own understanding, which builds the knowledge of the community of which they are a part. Google Wave met considerations of collaboration, learning how to learn and the idea of improvement considered essential for this knowledge building (van Aalst, 2006). Rather than simply sharing ideas, the students were able to treat ideas as objects of inquiry open to debate, scrutiny, investigation, and discussion rather than expert knowledge to be blindly accepted. This criticality is essential if the students are to move beyond a superficial knowledge of NOS to a deeper understanding where they are able to apply, analyse, and evaluate NOS (Allchin, 2011).

Since all postings remain, it is readily apparent that there was increasing participation as well as an increasing understanding of NOS concepts over the course’s duration. This relates to Lave and Wenger’s (1991) perspective of situated learning where the understanding is a result of ongoing construction, and that learning is a process of increasing participation in a community of practice (Lave & Wenger, 1991; Orgill, 2007). Analysis of the time and dates of the students’ postings shows
that this increasing participation was evident both in class and in their own time. One of the greatest benefits of this Web 2.0 technology is that after-class reflection was possible as the Wave is preserved and available for later viewing and reflection. Original postings are retained in chronological order. Students could, and did, add video clips, images, and further reflections or additional comments into any of the threads. Significant advantages were seen here. Firstly, all students could revisit the class session in their own time to consolidate understanding and realisations, and secondly, they could add further comments or media, thus creating a growing repository for the class. In terms of learning how to learn, this Web 2.0 technology went beyond being merely a discussion platform, to building a communal resource for learning (Scardamalia, 2002).

Those students who found that following the Google Wave while also trying to follow the lecturer was too demanding could, and did, reduce cognitive load by revisiting the Google Wave in their own time, at their own pace. This capacity to continue learning beyond class time fostered the construction of this knowledge-building community and the turning over of epistemic agency to the students. They were able to assume more responsibility for the advancement of their knowledge and inquiry (Damsa, Kirschner, Andriessen, Erkens, & Sins, 2010; Scardamalia, 2002).

Google Wave also provided a vehicle for feedback from the lecturer to the students and vice versa, and from the students to each other. In his synthesis of over 500,000 studies, John Hattie (2009) has identified high-quality feedback given against explicit criteria as having the greatest effect size on student achievement. While feedback informs the student, it should also inform the teacher, since knowing what the student knows or does not know is a key element in developing effective learning conditions. Hattie notes that:

> Increasing the amount of feedback in order to have a positive effect on student achievement requires a change in the conception of what it means to be a teacher. It is the feedback to the teacher about what students can and cannot do that is more powerful than feedback to the student (2009, p. 4).

Students’ postings provided direct and immediate information about student thinking to the lecturer, as valuable feedback about their learning. This enabled the lecturer to respond immediately when appropriate. This immediacy challenges the criticism that:

> The teacher is largely cut off from information about what individual students are learning. Teachers are forced to rely on secondary indicators such as the visible signs that students are motivated and interested... Teachers depend on the responses of a small number of key students as indicators and remain ignorant of what most of the class knows and understands (Nuthall, 2007, pp. 919–920.)

Google Wave provided an ongoing window for the lecturer into the conceptions and misconceptions of NOS which the students were holding.
As a limited-sample case study, the presented findings and conclusions cannot be used to generalise too broadly, but rather to serve as illustrative principles, strategies used, lessons learnt, and results achieved to help inform future mobile Web 2.0 projects in tertiary education. The student engagement, flexibility of learning contexts, and the quality of students’ contributions have led to the continuation of this research project.

While Google has discontinued development of Google Wave as a stand-alone product, there are other similar applications available, one of which is be trialled in the next phase of this research project where iPad devices are used. The ‘Waves’ already created by users will be stored in perpetuity, meaning that contributions made by this cohort continue to be available as a resource for them in their own teaching.

**Concluding Thoughts**

It is of critical importance to research effective ways for preservice teachers to develop NOS understanding in order to teach it in a transformed school science programme which engages and retains students’ interest in science and the development of their scientific literacy for them to realise fully the benefits of, and to participate in, an increasingly scientific society.

Since understanding NOS requires deep conceptual change rather than the acquisition of a superficial awareness of a few NOS tenets, a course design and pedagogy were required that acknowledged the current level of each participant’s conceptual knowledge and provided repeated opportunities for reflection and understanding. This was accomplished by structuring the course around repeated reflective opportunities using generic activities, reflective writing and Google Wave. This technology offered ongoing opportunities for in-class reflection – reflection that could be further deepened as the students were able to add to their postings outside class time. Students who found it cognitively too demanding to monitor NOS postings on the data projector screen and/or their own screen during the lecture, were able to revisit the session in their own time, at their own pace. This was invaluable for their learning.

By being able to add comments or rich media to their postings, these after-session postings were extended to conversations between students and authentic environments. It is the potential for mobile learning to bridge pedagogically designed learning contexts, facilitate learner-generated individual and collaborative contexts, while providing personalisation and ubiquitous social connectedness that sets it apart from more traditional learning environments (Cochrane, 2010).

Data show that the students’ NOS understanding developed over the duration of the course. Their
evaluation of Google Wave indicates that this was a valuable tool in deepening their understanding. It provided them with a platform for reflection, and enabled them to ‘converse with themselves’, creating a powerful means of exploring beliefs, attitudes, and learning. The key driver was the enhancement of teaching and learning, facilitating student-centred, social-constructivist pedagogies (Cochrane & Bateman, 2010). A learning community was created.

Broadly, the potential for learning with social software tools compels reconsideration of ways to conceptualise the dynamics of student learning. Sfard (1998) distinguishes between two metaphors of learning: as acquisition and as participation. The former represents a passive–receptive view according to which learning is mainly a process of acquiring chunks of information delivered, typically, by a teacher. The latter posits that learning is a process of participating in various cultural practices and shared learning activities. Paavola, Lipponen and Hakkarainen (2004) propose a third metaphor, that of learning as knowledge creation, which emphasises the dynamic nature of learning for transforming knowledge and practice. Web 2.0 technologies can provide the structure to meet these demands for knowledge creation.

This project’s goal has been to move pedagogical approaches in tertiary education from instructivist pedagogies to a social-constructivist pedagogy (Vygotsky, 1978b) and to facilitate a context-bridging, collaborative transformative environment. The proliferation of technological tools provokes us to consider how new modes of community-based sharing and content creation might be applied to the more formal learning spaces of colleges and universities (Berg, Berquam, & Christoph, 2007). This research project has shown the potential of a Web 2.0 tool to facilitate a change in the trajectory of student learning. While the directive for the teacher to be a ‘guide on the side’ as opposed to a ‘sage on the stage’ (Doolittle, 2003; King 1993) has been with us for many years, Web 2.0 equips us with new ways in which to realise this goal while continuing to recognise the role of the teacher as an expert.
Chapter 6: Using Technology as a Pedagogical Tool to Develop Understanding of NOS

Introduction
Students enrolled in the three-year programme of the Bachelor of Education in Teaching (Primary Specialisation) programme at the University of Auckland are required to take one semester-long science methods course in which a key emphasis is developing an understanding of the nature of science. Almost without exception, students enter this course with very limited understanding of NOS. The conceptual change required is therefore significant, and needs to occur within the short time frame of the course. However, research studies indicate that extended engagement with NOS ideas is required to allow ample time for the reflection needed to ensure adequate levels of understanding about NOS (Baird, Fensham, Gunstone, & White, 1991; Clough, 2002; Schwartz & Crawford, 2004).

Because extended time is not possible within the structure of the single semester timeframe, alternative means are required to provide repeated opportunities for the depth of reflection deemed necessary (Clough, 2006). This has prompted this examination of the use of Web 2.0 technologies as a teaching/learning tool to provide multiple opportunities for the repeated reflection required to effect conceptual change concerning NOS. Web 2.0 technologies provide new ways for people to collaborate, interact, communicate, co-create, and share ideas and knowledge (Hartshorne & Ajjan, 2009; Shihab, 2008).

This study reports on the second phase of ongoing research using Web 2.0 technology as a means of developing NOS understanding among preservice teachers. The first phase of this research, in 2010, used Google Wave (Heap, 2012). This second phase, used ShareFlow as a Web 2.0 forum which combines personal communication, instant messaging, wiki, and social networking, and was able to work in real-time throughout each session of the course.

Background
Recent decades have seen a shift in emphasis in science education from a focus on academic scientific education, specifically catering for the minority of students interested in pursuing careers in scientific fields, to giving prominence to preparing scientifically literate citizens who are capable of using science productively in their lives and of making informed decisions regarding science-related issues. An understanding of NOS as a crucial educational component of this scientific literacy is widely argued in the literature (e.g., Abd-El-Khalick & Lederman, 2000a; Bilican, Cakiroglu, & Oztekin,
Given the educational imperative of NOS, as a core component of scientific literacy (e.g. Hodson, 2011; Wahbeh & Abd-El-Khalick, 2014), it is of critical importance to research effective ways for preservice teachers to develop their own NOS understanding and their ability to teach NOS in a way which engages and retains students’ interest in science and fosters the development of their scientific literacy. A substantial body of research indicates that an explicit and reflective approach to NOS instruction can be effective in developing the type of understanding described in science education reform documents (e.g., Abd-El-Khalick & Akerson, 2004, 2009; Akerson & Hanuscin, 2007; Bell et al., 2011; Khishfe, 2008; Morrison et al., 2009; Posnanski, 2010; Schwartz, 2004; Smith & Scharmann, 2008).

However, for many students, this type of understanding requires substantial conceptual change, which in turn demands repeated opportunities for learners to examine their own views and identify the discrepancies between their own NOS conceptions and those presented in the course (Clough, 2006; Posner, Strike, Hewson and Gertzog, 1982). Teaching for conceptual change, here about NOS, requires that the target topic be made an explicit part of classroom discourse; that learners have structured opportunities to share, discuss and assess the consistency of their ideas; that discourse be metacognitive; that the status of ideas be negotiated and that justification of ideas be an explicit component of the course (Hewson et al., 1998). Frequent opportunities to experience, discuss and reflect on various aspects of NOS are needed in order to achieve the desired conceptual change. This is problematic given the short time frame of preservice teacher education programmes in general, and the even shorter time frame of the science education component of such programmes.

This problem of severe time constraint has led the researcher to examine the use of Web 2.0 technology as a means to ascertain the current level of each preservice teacher’s conceptual knowledge of NOS and to provide repeated opportunities for reflection and developing understanding. Background literature informing the use of Web 2.0 technology in education, in this instance as a pedagogical tool for developing understanding of the NOS, can be drawn from many areas, including the growing educational interest in Web 2.0 applications, the use of Web 2.0 to develop a community of practice, Web 2.0 as a tool for developing collective cognitive responsibility, and Web 2.0 to enhance feedback.

**Growing educational interest in Web 2.0 applications**

During the past decade, the nature of the Web and the ways in which people access and use web resources for personal, educational, employment, entertainment and other social purposes, have been fundamentally changed; from the passive retrieval of information by the user (Web 1.0) to the
participatory use of the Web as a read/write platform (Web 2.0) to broaden users’ communication capabilities and enable content distribution, sharing, co-creation, and remixing through participatory practices (Jimoyiannis, Tsiotakis, Roussinos, & Siorenta, 2013). Whereas the communication paradigm of Web 1.0 technology is characterised by one-way communication, one-to-many, low or non-existent interaction where users are limited to the passive viewing of content others have created, the Web 2.0 communication paradigm is many-to-many, with interaction between all the participants as a space for critical dialogue and collaboration, where users assume the role of not only consumers but also producers of content.

Web 2.0 is now a collective term for a series of Web-based technologies that include blogging and microblogging platforms, wikis, media-sharing sites, podcasting, content aggregators, social networks, social bookmarking sites, and other emerging forms of participatory and social media. Since these all support active participation, connectivity, collaboration and sharing of knowledge and ideas among users, it is evident why Web 2.0 technologies have generated increased educational interest. Indeed, the use of Web 2.0 is expected to exert a significant impact on instruction and learning for the multiple opportunities it provides for students’ engagement, communication, active and self-directed learning, collaborative learning, sharing of content, ubiquitous and life-long learning (Dede, 2008; McLoughlin & Lee, 2010; Glassman & Kang, 2010). In addition, Web 2.0 technologies extend students’ learning spaces (both physical and virtual) beyond the walls of the classroom and can build learning and instruction bridges across school, home, and the wider community (Jimoyiannis, 2010).

Jimoyiannis, Tsiotakis, Roussinos, and Siorenta (2013) propose that one of the most compelling arguments for the use of Web 2.0 in tertiary education is the apparently changing nature of the generic student who comes to the university already highly connected and therefore with a readiness to adopt Web 2.0 as an effective learning environment. Indeed, the majority of young people are already engaged by Web 2.0 in their personal and social lives out of school (e.g., social networking). Crook (2008) argues that Web 2.0 technology was only symptomatic of an already present disposition toward practices common in communication today.

A second compelling argument for the use of Web 2.0 in education comes from advances in learning theory. An important emphasis in recent years has been on active construction of knowledge by the learner, the importance of prior experience, the fitting of knowledge into existing schema or the establishment of new schema, and the active processing of information - all as components of a learning model that emphasises high learner involvement (Chism, 2006). It is argued that environments able to provide experiences, stimulate the senses, encourage the exchange of information, and offer opportunities for rehearsal, feedback, application, and transfer are most likely to support learning – and Web 2.0 can provide this environment. Similarly, McLoughlin and Lee (2010) commented on the affordances and principles of social software as a pedagogical choice. They
argued that one of social constructivism’s foremost tenets, that learning is conversational in nature, including dialogue and shared activity (Vygotsky, 1978a), can be applied to teaching with Web 2.0.

This research study examines the educational affordances of the Web 2.0 application ShareFlow to support learner involvement, participatory collaboration and the sharing of knowledge to develop conceptual understanding – in this instance of NOS.

**Web 2.0 to enhance community of practice**

Based on her research on learning communities outside of schools, Lave argues that learning is about constructing “identities in practice” (1996, p. 157). Identities practiced in such communities are always a work in progress shaped by individual and collective efforts to create coherence through participation in varied social contexts. Wenger (1998) also views learning as arising from the identity work that occurs through participation in communities of practice (COP), communities “created over time by the sustained pursuit of a shared enterprise” (p. 45). Since Lave and Wenger’s (1991) seminal book on communities of practice, it has become generally accepted to look at the community in which action is situated as an essential mediating artefact of action. This is particularly true when viewing communities of practice designed to support learning (Barab, Kling, & Gray, 2004).

The COP view of learning is that learning is not exclusively a mental act but rather is a social act, set in a participatory social context and dependent upon interaction among people and their tools and technologies (Lave, 1996; Rogoff, Baker-Sennett, Lacasa, & Goldsmith, 1995; Wenger, 1998). Lave and Wenger’s (1991) perspective of situated learning proposes that understanding is a result of ongoing construction, and learning is a process of increasing participation in a community of practice (Lave & Wenger, 1991; Orgill, 2007). The use of social media to enhance the community of practice in the university classroom makes for a logical argument. Indeed, Hung and Yuen (2010) contend that a sense of community is an essential element for successful e-learning.

The quality of the Web 2.0 interface is also critical in a situated learning, COP model. Kling, McKim and King (2003) use the term *socio-technical interaction networks* (STIN), referring to a framework for conceptualising human behaviour that occurs in technology-mediated social settings. The strength of the STIN framework is its base assumption that all technical structures must be understood as part of the context of social transaction through which they are constituted and through which they take on their meanings. Social and technical nodes are both part of a dynamic teaching/learning system.

This research study investigated the potential for Web 2.0 technology to enhance the COP and foster learning of NOS through increasing participation in this student teacher community.
Web 2.0 to enhance collective cognitive responsibility

Having students become active agents in knowledge construction is an important and constantly recurring theme in the learning sciences literature (e.g., Engle & Conant, 2002; Herrenkohl & Guerra, 1998; Lehrer, Carpenter, Schauble, & Putz, 2000; Paavola & Hakkarainen, 2005; Scardamalia & Bereiter, 1994; Tabak & Baumgartner, 2004). Collective cognitive responsibility combines high levels of social as well as cognitive responsibility, engaging students in what knowledge-creating groups do in innovation-generating organisations (Bereiter & Scardamalia, 2003b).

To assume these levels of social and cognitive responsibility, students must recognise that their own ideas, like ideas in general, can be continually improved. They do this by collectively working toward deeper explanations and higher-level conceptualisations that give them greater explanatory power (Thagard, 1992). Additionally, student ideas must have an ‘out-in-the-world’ existence (Bereiter, 2002; Goldman & Scardamalia, 2013). They are not equivalent to personal knowledge or beliefs; rather, theories, inventions, models, plans – the intellectual life of the community – are accessible as knowledge objects to all, and are all improvable knowledge.

Collective cognitive responsibility also requires that members advance the joint enterprise, in the context of joint activity (Koschmann, 2002). Mutual engagement thus “involves not only our competence, but also the competence of others. It draws on what we do and what we know, as well as on our ability to connect meaningfully ... to the contributions and knowledge of others” (Wenger, 1998, p. 76). Members in a knowledge-building community must accordingly make complementary contributions. It is important to respond to and build on one another’s ideas (Palincsar, Anderson, & David, 1993) and contribute non-redundant and key information that advances the enterprise as a whole.

Collective cognitive responsibility also requires teachers to relinquish their long-held role as the sole engineer of the learning process and turn strategic cognitive activity over to the students (Scardamalia, 2002). Of course, not much can be done to turn more responsibility over to the students unless the structure of classroom discourse is changed. Small group work is one strategy that can be used effectively to transfer greater responsibility for learning to the students. But it is not without its drawbacks, including the tendency for group discussion to be dominated by the more vocal and socially dominant students, and the need to share the knowledge generated in one group with all the others (Scardamalia, 2004). These problems of discourse structure prompted Scardamalia and Bereiter to investigate the possibilities of using Web 2.0 technology to instigate change. Their first prototype of CSILE (Computer-Supported Intentional Learning Environments) was implemented in 1983 in an undergraduate developmental psychology course of over 300 students at York University. From this pioneering work in computer supported collaborative learning, Bereiter and Scardamalia developed the theory of “knowledge building”, which attempts to “refashion education in a fundamental way, so
that it becomes a coherent effort to initiate students into a knowledge creating culture” (Zhang, Scardamalia, Reeve, & Messina, 2009, p. 97). In this context, the Internet becomes more than a desktop library and a rapid mail-delivery system. It becomes the first realistic means for students to connect with global knowledge building and to make their classroom work a part of it.

Conceptually, the main difference between Scardamalia’s notion of knowledge building and other forms of constructivist teaching in learning communities is its emphasis on the importance of ideas as objects of inquiry and improvement in their own right (Scardamalia & Bereiter, 2003b). Knowledge building looks to make the shift from students being learners and inquirers to students being members of a knowledge-building community (Scardamalia & Bereiter, 2006). The core motivation of activities is to identify and advance the frontiers of knowledge and to produce ideas that are of value for the learning community. “The key distinction is between learning – the process through which the rapidly growing cultural capital of a society is distributed – and knowledge building – the deliberate effort to increase the cultural capital of society” (Scardamalia & Bereiter, 2003b, p. 1371).

This research study investigated the use of Web 2.0 technology to shift emphasis away from the individual student’s acquisition of a deeper understanding of NOS, to a collective cognitive responsibility within the class; that is, a joint enterprise in which class members made contributions and recognised NOS ideas as being improvable objects.

**Web 2.0 to enhance feedback**

Hattie (2009) synthesised some 800 meta-analyses of 52,637 individual quantitative studies of variables affecting the achievement of students, in order to identify a statistical index for effect size. Identifying 146,000 effect sizes, he concluded that the three strongest single factors impacting student achievement are self-reported grades, Piagetian programmes, and providing formative feedback. On feedback, he contends that “What is most important is that teaching is visible to the student and that the learning is visible to the teacher” (p. 25).

Hattie conceptualises feedback as information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one’s performance or understanding. To be most effective, feedback needs to provide information specifically relating to the task or process of learning that fills a gap between what is understood and what is aimed to be understood (Sadler, 1989), and it can do this in a number of different ways. The first is through affective processes, such as increased effort, motivation or engagement. Second, through a number of different cognitive processes, including restructuring understanding, confirming to students that they are correct or incorrect, indicating that more information is available or needed, pointing to directions students could pursue, and/or indicating alternative strategies to understand particular information. Winne and Butler (1995) posit that “feedback is information with which a learner can confirm, add to, overwrite, tune, or restructure
information in memory, whether that information is domain knowledge, metacognitive knowledge, beliefs about self and tasks, or cognitive tactics and strategies” (p. 5740).

Clearly, if as Hattie (2009) posits, feedback is one of the three strongest single factors impacting student achievement, it warrants our attention in science teacher education. Providing such feedback in traditional tertiary education settings can be problematic, particularly given the large size of classes and the short duration of courses. In an earlier synthesis of 74 meta-analyses that included information about feedback (across more than 7,000 studies and 13,370 effect sizes), Hattie (2009) demonstrated that “the most effective forms of feedback provide cues or reinforcement to learners; are in the form of video-, audio-, or computer assisted instructional feedback; and/or relate to goals” (p. 84).

This study examined the use of the Web 2.0 platform ShareFlow as a tool to provide feedback on students’ understanding of NOS. The use of ShareFlow provided repeated opportunities for feedback on ideas about NOS. This feedback was multidirectional: from the student to the lecturer; from the lecturer to the students; from the students to each other.

Research Design

This study used a convergence triangular mixed-methods design, in which different but complementary data were collected to validate and expand quantitative results with qualitative data (Creswell & Clark, 2007). The research is the second phase of an ongoing study investigating the use of Web 2.0 to develop students’ understanding of NOS. A case study approach was adopted for its capacity to focus on dynamics within a single setting and provide rich description (Huberman & Miles, 2002).

The research participants were preservice primary school teachers, that is, students enrolled in the three-year Bachelor of Education (Primary Specialisation) University degree programme (n=39). The science course is one semester long, in the second year of the programme, and is the only compulsory science education course in their degree.

The course content covered all five strands of the New Zealand science curriculum: the four contextual strands, namely: Living World, Material World, Physical World, Planet Earth and Beyond (Geology and Astronomy) plus the Nature of Science strand, described in the curriculum as the “overarching, unifying strand” (Ministry of Education, 2007a, p. 9) to be taught through the four major contexts in which scientific knowledge has developed and continues to develop (see Appendix A).

In order to research the effectiveness of Web 2.0 to develop NOS understandings, all students were loaned an iPad for each session, or brought their own device. Throughout each session, the students were asked to identify aspects of NOS which were taught explicitly by the lecturer, or covered
implicitly in the course content, or which the session content caused them to consider. When students made a NOS-related observation, they could enter a brief comment into the relevant ShareFlow session using their iPads or other personal mobile devices. These were immediately visible, on a large screen via a data projector and on each student’s own device via the ShareFlow platform. Other students and the lecturer were then able to read all the ShareFlow comments, at appropriate moments, as the session was progressing, and to add their own responses if they chose. Students were also encouraged to add to these comments in their own time after the sessions. They could also upload web images and video clips (e.g., from YouTube) alongside relevant comments which they or another student had already entered on the ShareFlow platform.

Data Collection and Analysis

Students’ developing understanding of NOS, and their use of ShareFlow were monitored through the following data:

- Students completed a Views of Nature of Science, form C (VNOS-C) questionnaire (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) before the course began and again as a repeated measure at the end of the course (see Appendix C).
- All ShareFlow postings made by the students during each session remained as a growing repository and could be analysed. Contributions made by the students through ShareFlow after the lectures, during their own study time, were also tracked and analysed.
- The Cognitive Communication Questionnaire (Andrade, Castro, & Ferreira, 2012) was modified with the Audience Response Technology Questionnaire (MacGeorge et.al., 2008) and was used to evaluate four dimensions of ShareFlow, namely: i) engagement, ii) learning, iii) student interaction and iv) technology (see Appendix D and Table 6.5).
- As part of an assessment task, students planned a teaching unit incorporating NOS teaching.
- Test questions at the end of the course covered NOS content.
- All students completed the standard University Course Evaluation.

Data from the first three measures is reported in this chapter to explore the effectiveness of Web 2.0 technology to develop conceptual understanding of NOS.

Findings

Having students become active agents in knowledge construction about NOS requires that they recognise that their own ideas, like ideas in general, can be continually improved. The feedback the students receive, and provide, when they post their ideas about NOS to a collective forum allows them to build on each other’s ideas and develop deeper explanations and higher-level conceptualisation – here, of NOS.
The centrality of feedback in this knowledge building prompts this section to open with the analysis related to feedback. Second, ShareFlow postings are analysed for evidence of community of practice, and third, analysed for the effectiveness of ShareFlow in enhancing collective cognitive responsibility concerning ideas about NOS. The fourth section of analysis examines the VNOS results for any shifts in NOS ideas. Finally, student evaluation of the ShareFlow tool itself is presented.

Enhancing feedback

In each session, the students were asked to make a brief post whenever they identified an idea about NOS – in the lecturer talk, in group discussions, or in the practical activities of each session. This was, in effect, a virtual classroom about NOS which ran simultaneously with the lecture or workshop session. The first session was focused entirely on NOS (see Table 6.1). In each session, students’ posts showed comments that related to:

- Features of NOS (Matthews, 2012)
- Tenets of NOS (e.g., Lederman, 1992)
- The NOS aims and objectives for the NOS strand in the New Zealand Curriculum (Ministry of Education, 2007b) (see Appendix E)
- Broader goals for science education (e.g., Allchin, 2012; Bencze, 2010; Hodson, 2011; Zeidler & Sadler, 2008)

All of the students’ online postings remained visible for the duration of the course (or longer if desired). This repository of postings was analysed for instances of feedback. Three types of feedback were identified: feedback from the students to the lecturer, feedback from the lecturer to the students and feedback from the students to one another.

Counts were made of each instance of feedback for each session (14 sessions in total). The lecturer also kept a journal note of each time she gave verbal feedback to the class in response to a student’s post. The results of this analysis are given in Table 6.1 and Figure 6.1. Session 1 was an introductory session on NOS. Between sessions 5 & 6 were 2 weeks of school-based instruction and one-week of study break.
Table 6.1 Instances of feedback using ShareFlow

<table>
<thead>
<tr>
<th>Session number</th>
<th>Session topic</th>
<th>Instances of feedback recorded</th>
<th>Total feedback posts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Nature of Science</td>
<td>37 3 11</td>
<td>51</td>
</tr>
<tr>
<td>2</td>
<td>Material World – Physical Change</td>
<td>10 3 7</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Material World – Chemical Change</td>
<td>12 6 5</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>Material World – Dissolving</td>
<td>11 7 8</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>Children’s misconceptions in science</td>
<td>18 4 7</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>Nature of Science</td>
<td>19 20 21</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>Investigations</td>
<td>22 23 24</td>
<td>69</td>
</tr>
<tr>
<td>8</td>
<td>Investigations</td>
<td>23 35 8</td>
<td>64</td>
</tr>
<tr>
<td>9</td>
<td>Physical World – Heat</td>
<td>28 21 10</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>Physical World – Sound</td>
<td>37 28 6</td>
<td>71</td>
</tr>
<tr>
<td>11</td>
<td>Planet Earth &amp; Beyond – Rocks</td>
<td>32 44 7</td>
<td>83</td>
</tr>
<tr>
<td>12</td>
<td>Planet Earth &amp; Beyond – Tectonic</td>
<td>28 51 6</td>
<td>85</td>
</tr>
<tr>
<td>13</td>
<td>Animal Classification</td>
<td>22 48 7</td>
<td>87</td>
</tr>
<tr>
<td>14</td>
<td>Animal Processes</td>
<td>20 55 6</td>
<td>81</td>
</tr>
</tbody>
</table>

Figure 6.1 Instances of feedback using ShareFlow

\[ R^2 = 0.92206 \]

\[ R^2 = 0.95046 \]
Table 6.1 and Figure 6.1 show the overall trends in feedback over the duration of the course; from students to lecturer, from lecturer to students and from students to each other. The high number of student to teacher feedback responses in session 1 can be attributed to the content of that session (the nature of science) and to the learning intention of the session: that each student would make at least one post to familiarise themselves with the technology. In general, sessions 2-10 show an increase in instances of student to teacher and of student to student feedback. It is the student to student feedback which shows the greatest increase. For example, during session 7 the students carried out a range of investigations, of the type they could do in their own teaching practice. One of these was to design an investigation to test the crunchiness of three types of potato chips. This led one student to post,

You could use this investigation as an attention grabber / starter activity / hook for a health topic on obesity. (S5, Post, Session 8)

This post prompted the following string of comments, each of which was entered as the students were conducting their investigations.

Clever. Showing that science is relevant. (S1, Post, Session 8)

SO it fits the Achievement Aim from the curriculum, “Bring a scientific perspective to decisions and actions as appropriate.” (S34, Post, Session 8)

And if you used context of obesity, what about learning “about the ways in which the work of scientists interacts with society.” (S7, Post, Session 8)

I agree. Research funding in NZ to diabetes???? (S14, Post, Session 8)

I remember another investigation from school – burning a peanut to investigate. Could do that too. (S5, Post, Session 8)

Or could look at nutritional labels on chippie packets. “Develop and use science knowledge to interpret.” (S28, Post, Session 8)

Science as evidence for an opinion. (S19, Post, Session 8).

This would help “link their science learning to their daily living.” (S8, Post, Session 8)

I’m observing. That’s empirical NOS. (S26, Post, Session 8)

Creativity needed to design investigation. (S32, Post, Session 8)

And interpret results. Ha. (S11, Post, Session 8)

Relate to food additives. Pros and cons. (S17, Post, Session 8)

Chippie food waste at McDonalds. (S36, Post, Session 8)

Crunchy potato chip First World problem - vs. using science to address global food shortage. (S3, Post, Session 8)

Endless options. Just need imagination!!! (S10, Post, Session 8)

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10 Throughout the data analysis, comments will be referenced as Student number, Source of comment, Session number. So ’S5, Post, Session 16’ is a comment made by Student 5 as an online post during session 16.
Student 5’s initial comment is categorised as Student to Teacher because it is a response to the task of being asked to identify NOS in the session. The subsequent eight responses are categorised as Student to Student since they are replies to S5’s initial post. Students 26, 32, 11, 17 and 36 each made ‘new’ posts, categorised as Student to Teacher. Student 10 is responding to Student 3 (and perhaps to earlier posts) and so is categorised as Student to Student.

It can be seen from Figure 6.1, that towards the end of the course, sessions 11 onwards, the trend lines show that while student to student feedback increases, student to teacher feedback decreases. While the students did continue to make posts on their NOS ideas as prompted by teacher comments or actions (student to teacher feedback), they were responding more with posts on their NOS ideas as prompted by fellow students’ comments (student to student feedback). Over the same period, specific teacher to student feedback, on ShareFlow, decreased slightly – as the students themselves assumed this role, and the need for the teacher alone to provide the feedback lessened.

**Enhancing community of practice**

The use of Web 2.0 to enhance the incipient community of practice in this university classroom is evidenced here by the students’ increasing participation in this web-based community (Lave & Wenger, 1991). Table 6.2 and Figure 6.2 show the total number of posts each session and indicate increasing participation, as is evidenced by the fourfold increase from 20 posts in session 2 to over 80 posts in the final session. The data also show how many of these posts were unique, i.e., made by different students. In the first session, 11 students contributed posts; by session 11, participation had increased to 37 students; in the final two sessions, all students contributed posts on ShareFlow.

This is not to say that non-posting students were non-active. For example, since the students all sat in table groups of 5–6 students, a table group (or smaller group) could have discussed a NOS idea which only one of the group then posted. Nonetheless, Table 6.2 and Figure 6.2 do show increasing participation by the students, a distinguishing feature of COPs both in the total number of posts and in the total number of unique posts, as they moved from legitimate peripheral participation to full participation.

It should be noted that the posting of NOS-related comments, such as posts regarding instances of NOS the students observed, thoughts about NOS they wanted to share, comments about NOS prompted by the posts of others etc., did not replace group or class discussion on NOS. Such discussions still occurred in the same way as in classes without ShareFlow, and indeed were often prompted by the ShareFlow postings. ShareFlow provided an additional, not a replacement platform for discussion.
Table 6.2 Student participation on ShareFlow

<table>
<thead>
<tr>
<th>Session number</th>
<th>Total number of posts</th>
<th>Number of unique posts</th>
<th>% of class (n=39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>14</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>18</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
<td>21</td>
<td>54</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>26</td>
<td>67</td>
</tr>
<tr>
<td>7</td>
<td>69</td>
<td>28</td>
<td>72</td>
</tr>
<tr>
<td>8</td>
<td>64</td>
<td>26</td>
<td>67</td>
</tr>
<tr>
<td>9</td>
<td>59</td>
<td>31</td>
<td>79</td>
</tr>
<tr>
<td>10</td>
<td>71</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td>11</td>
<td>83</td>
<td>34</td>
<td>87</td>
</tr>
<tr>
<td>12</td>
<td>85</td>
<td>37</td>
<td>95</td>
</tr>
<tr>
<td>13</td>
<td>87</td>
<td>39</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>81</td>
<td>39</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 6.2 Student participation on ShareFlow

**Collective cognitive responsibility**

Analysis of ShareFlow postings shows that almost all instances coded as student to student feedback (see Table 6.1 and Figure 6.1) are examples of students improving on the ideas of others and thus of growing collective cognitive responsibility. The series of posts that follows, from session 2, provides examples of this shared collective improving of knowledge. Student 2 mentions observation, which other students then build upon, contributing to increasing precision, scope and sophistication as they
engage with the thoughts of other students. This string of posts is one example of the increasing sophistication of ideas that was regularly seen in the students’ responses.

On the role of observation in science: We visually observed a change of state – the milk (liquid) becoming ice cream (solid) and then tried to explain it. We also observed that solid ice cream melting back to liquid after a while. (S2, Post, Session 2)

Observation can also be non-visual – feeling the temperature of the liquid getting colder, the increasing hardness of the ice cream. (S27, Post, Session2)

Technology can help in reporting of observation – e.g., ‘Melted after a while’ could become ‘melted completely after 2 minutes’ if you had a stopwatch. (S31, Post Session 2)

‘Completely’ would be hard to nail down. (S24, Post Session 2)

What about a thermometer and a stopwatch. ‘Reached room temperature, 23 deg, after 2 mins 23 secs?’ (S31, Post, Session 2)

Nice. (S24, Post, Session 2)

I think observations will always depend on the observer – and nobody’s senses are perfect are they? So observations may not be totally reliable. (S12, Post, Session 2)

And knowledge always tentative (S39, Post, Session 2)

Some of the words we use to describe observations aren’t observational words. Like ‘Melting.’ It has a whole concept behind it and we all just accept that we know what it means. We all know what melting is so we use the word as a given. It’s not an observation it’s a whole theory. (S14 Post, Session 2)

So what comes first? Theories or observations. (S19, Post Session 2)

The chicken of (sic.) the egg? (S9, Post, Session 14)

How powerful a microscope would we need to use to see what is happening to the molecules? What’s really going on here? Why does something go hard when it freezes? (S18, Post, Session 2)

I don’t think any microscopes let us see that. I don’t think anyone has ever seen a molecule or atom. (S6, Post, Session 2)

What???? (S18, Post Session 2)

These posts prompted a class discussion in session 2 on the role of observation in science: fallibility in observation; observations as theory dependent; competing theories in observation; tentativeness and durability of scientific knowledge; influence of prior knowledge, experience, ideas and expectation on observation; instrumentation; and the inadequacy of induction as sole scientific method.

**Prompting shifts in NOS understanding**

ShareFlow, as a Web 2.0 technology, was used in this course as a pedagogical tool to examine its potential to provide multiple opportunities for the reflection required to effect conceptual change.
concerning NOS. The Views of Nature of Science Questionnaire (VNOS-C), an open-ended instrument developed by Lederman et al. (2002), was chosen as the primary data-gathering instrument for students’ pre- and post- understanding of NOS (see Appendix C for full questionnaire).

The qualitative data analysis of VNOS-C is interpretive and focuses on the meanings that participants give to the selected aspects of NOS. The general approach to the analysis of participant responses to the VNOS-C was inductive, as described by Patton (2002) and Bogdan and Biklen (1998). Classification schemes from numerous studies using the VNOS-B or VNOS-C instrument were examined. Most used three categories for coding responses, for example:

- No understanding / Emerging (described as some understanding with persistent misconceptions) / Informed (described as contradictory answers present in responses) (Akerson et al., 2007);
- Contradictory to reform characterisations / Aligned with reform characterisations / Enriched view (Hanuscin, Akerson, & Phillipson-Mower, 2006);
- Naïve / Synthetic / Informed (Vosniadou, 1999); Uninformed/Syncretic/Informed (Jones, 2010).

The terms naïve and informed were chosen as category titles because they are described and frequently used in the literature.¹¹ Jones’ ‘syncretic’ was chosen as the descriptive term for the scoring category to represent the transition of participant understanding from naïve to informed. Jones (2010) describes this term as often used in reference to religious or philosophical belief systems that are a combination of different, and at times contradictory, beliefs or practices. When used as a coding category in this study, it describes “a participant holding on to different beliefs, views, and understandings of science simultaneously and at times holding some in abeyance depending on context” (Jones, 2010, p.78).

The VNOS-C questionnaire consists of eight questions. Pre- and post- VNOS responses were analysed and coded for naïve/syncretic/informed expressed understanding of six of the widely used tenets of NOS. Use of these tenets is not intended to convey a restrictive notion of NOS; rather, it is for analytical purposes and for consistency with many other published studies. Each of the six NOS tenet/aspects was targeted in more than one item in the questionnaire. In order for a participant’s view on any aspect to be categorised as informed, they had to provide evidence for an informed view in all of their responses related to the aspect. A view was categorised as naïve when the participant could not exhibit any informed view on the targeted aspect of NOS in response to any item in the

questionnaire. If any participant demonstrated informed views in response to some but not all items, then the view was categorised as syncretic. All questionnaires were read and coded three times for each target aspect of NOS to ensure consistency. A second rater coded 23% of the surveys to determine inter-rater correlation (85.4% consistency for the pre-questionnaire and 89% for the post-questionnaire).

A profile of each student was created using the pre- and post-course surveys. The profiles provided a picture of each learner’s NOS views and were used to examine overall class trends rather than changes in individuals’ views. Table 6.3 and Figure 6.3 show the percentages of naïve, syncretic and informed views of the selected NOS aspects, pre- and post-instruction.

Table 6.3 Pre- and post-views of selected NOS aspects

<table>
<thead>
<tr>
<th></th>
<th>Empirical NOS</th>
<th>A single scientific method</th>
<th>Tentative nature of scientific knowledge</th>
<th>Subjective &amp; theory laden NOS</th>
<th>Creative / imaginative/inferential NOS</th>
<th>Socially &amp; culturally embedded NOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From VNOS items: 1, 2, 4, 6,</td>
<td>From VNOS items: 1, 5, 6, 7</td>
<td>From VNOS items: 1, 2, 3, 4</td>
<td>From VNOS items: 1, 2, 3, 4</td>
<td>From VNOS items: 1, 2, 7</td>
<td>From VNOS items: 1, 2, 6</td>
</tr>
<tr>
<td>(n=39) Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Naïve</td>
<td>43.5</td>
<td>0</td>
<td>82</td>
<td>0</td>
<td>30.7</td>
<td>0</td>
</tr>
<tr>
<td>Syncetic</td>
<td>41.0</td>
<td>10.2</td>
<td>7.7</td>
<td>7.7</td>
<td>43.5</td>
<td>12.8</td>
</tr>
<tr>
<td>Informed</td>
<td>15.3</td>
<td>89.8</td>
<td>10.2</td>
<td>92.3</td>
<td>23.1</td>
<td>87.2</td>
</tr>
</tbody>
</table>
Figure 6.3 Pre- and post-views of selected NOS aspects

As shown in Table 6.3, the majority of the participants initially expressed naïve views of the NOS aspects of a single scientific method, science as subjective and theory laden, and science as being socially and culturally embedded. Furthermore, the majority of the participants expressed naïve or syncretic understandings of each of the other NOS aspects, namely that science is empirically based, scientific knowledge is tentative and that science is inferential, creative and imaginative.

The post-course results showed a shift in expressed views of each of the selected NOS tenets. The number of participants categorised as holding naïve views decreased to zero for each tenet. Conversely, the number of participants categorised as holding informed views increased for each tenet. The most significant shifts were seen in the understanding that there is no single scientific method that all scientists follow in all circumstances, and that science is socially and culturally embedded.

Tracking individual students is beyond the scope of this reporting. Rather, selected responses that are representative of pre-course and post-course naïve and informed responses of each of the selected tenets are given in Table 6.4. Shifts in NOS views were also evident over the duration of the course in the ShareFlow posts.
<table>
<thead>
<tr>
<th>NOS characteristic</th>
<th>Representative response for ‘naïve’ category</th>
<th>Representative response for ‘informed’ category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science is empirically</td>
<td>Science is based on observations obtained from experiments and data to provide facts and evidence. Scientists collect data and make observations to make claims and theories. A theory needs evidence in order to prove it right or wrong (S30, Pre-VNOS-C, Session 1).</td>
<td>Science is empirically based – direct or indirect observation, with any of our senses (unaided) or using technology to further our sense (e.g., microscopes and telescopes or sight, stethoscopes for hearing). Any explanations must be consistent with the observable evidence (S35, Post-VNOS-C, Session 1).</td>
</tr>
<tr>
<td></td>
<td>Scientists examine data they observe and from this discover the theories and laws that explain how things work and why things are as they are (S8, Pre-VNOS-C, Session 1).</td>
<td>Science is the endeavour of empirical explanations of the world. Comprises the collection of data and the drawing of inferences. Science is a tool to explain the natural, but not the supernatural, world (S17, Post-VNOS-C, Session 1).</td>
</tr>
<tr>
<td>Scientific knowledge</td>
<td>Science is facts and research that have been proven true by scientists. Fixed (S21, Pre-VNOS-C, Session 1).</td>
<td>Scientific knowledge will change. As time goes on and mankind advances their thinking, we come up with new tools to investigate, which essentially leads to new lines of evidence being found and changing previous scientific knowledge. It can also change because existing evidence is interpreted differently. That said, scientific understanding is enduring and robust. e.g., Newton’s laws of motion explain how space rockets work (S28, Post-VNOS-C, Session 1).</td>
</tr>
<tr>
<td></td>
<td>Science is what we accept as fact based on physical evidence and/or as a result of thorough testing; indisputable knowledge (S18, Pre-VNOS-C, Session 1).</td>
<td>The history of science has shown that knowledge is a constantly evolving thing as new evidence becomes available or new minds approach what we already know. People once were sure that flies sprang magically to life from dungheaps, for example, and then we pieced together their lifecycles. But we still do not absolutely know where life comes from and as we apply new creative thought to this question and design new experiments and theories we will probably develop our ideas and this will change a lot of what we know about living things. (S5, Post-VNOS-C, Session 1).</td>
</tr>
<tr>
<td>is tentative, but durable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjective and theory</td>
<td>Scientists’ approach to their science is always objective. Science is a search for answers with findings examined and dissected by peers (S12, Pre-VNOS-C, Session 1).</td>
<td>Because, while science is based on evidence, it relies on interpretation of evidence – and it is people who have to make these interpretations &amp; people can be inherently unreliable as we are subject to all kinds of biases etc. (S1, Post-VNOS-C, Session 1).</td>
</tr>
<tr>
<td></td>
<td>Science must always be objective since the hypotheses, experiments &amp; investigations need to be able to be repeatedly replicated by other scientists in independent laboratory conditions. If other scientists don’t reach your same conclusions it is no longer scientific (S6, Pre-VNOS-C, Session 1).</td>
<td>Because evidence is able to be interpreted in different ways. Scientists bring their own previous notions and bias to any interpretation and it is impossible to distance oneself from these influences. No one is ever completely neutral. Sociocultural factors are going to have the most influence on a person’s worldview and these will give rise to differing interpretations (S10, Post-VNOS-C, Session 1).</td>
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</table>
Socially and culturally embedded

Science does not reflect political values, philosophical assumptions and intellectual norms... They are cold hard facts (S4, Pre-VNOS-C, Session 1).

Science is universal. Values & norms are not the essence of science (S15, Pre-VNOS-C, Session 1).

Creative

Scientists do not use creativity or imagination because it would destroy their objectivity (S23, Pre-VNOS-C, Session 1).

Scientists have to think about how they will discover facts but the actual experiment is a set method that must be followed exactly and cannot be altered (S19, Pre-VNOS-C, Session 1).

One scientific method

Science relies on using the scientific method of Hypothesis, research, investigation, experiments, results, conclusions (S35, Pre-VNOS-C, Session 1).

Scientists use the scientific method in their research. Scientific knowledge requires experiments. Developing a hypothesis to test. Planning how to test it. Testing hypothesis. Collecting data & deciphering data. Conclusion (S15, Pre-VNOS-C, Session 1).

Science reflects the culture around it because the world is examined through those assumptions. Scientists may try to remove themselves from these biases, but they will never be able to be completely objective (S39, Post-VNOS-C, Session 1).

Science is influenced by society. Interpretations, inferences and every decision regarding what will be explored are all shaped by scientists’ pre-existing understandings, which are shaped by their society. We ask questions and seek answers which reflect the values of our societies (S31, Post-VNOS-C, Session 1).

I think creativity plays a role in each stage of the process. Planning requires creativity to create an experiment and a method of carrying it out. Data collection requires careful creativity in order to interpret and say something about the data. Science is interested in forming new solutions so creativity is a must to think up alternatives (S38, Post-VNOS-C, Session 1).

Scientists use imagination and creativity at every stage. They need imagination and creativity in order to think outside the box in how they want to discover about the world, how to look at the world to find this, and how to analyse results (S4, Post-VNOS-C, Session 1).

There are many different approaches to finding out scientific knowledge (S20, Post-VNOS-C, Session 1).

Scientific knowledge can be garnered from investigations, surveys, observations and research e.g., meta-analysis of pre-existing data; library based research etc. (S33, Post-VNOS-C, Session 1).

Student evaluation of ShareFlow

In order to provide data to discuss the impact (or not) of using Web 2.0 technology to facilitate the development of NOS understanding, an instrument was required to evaluate student use of ShareFlow. However, literature reviews (e.g., Han & Finkelstein, 2013; Kay & LeSage, 2009; Penuel, Boscardin, Masyn, & Crawford, 2007) have suggested that the basis for understanding the effects of computer assisted feedback on students has been mostly anecdotal. Most measure students’ perceptions of computer-assisted feedback as engagement and learning with only one or two items, and often disregard issues of validity and reliability (Han & Finkelstein, 2013).

MacGeorge, Homan, Dunning and colleagues (2008) responded to this critique by developing the
Audience Response Technology Questionnaire (ART-Q), a multidimensional scale with multiple items for each dimension, with established construct validity and reliability. Similarly Andrade et al. (2012) developed a questionnaire consisting of 41 items spread across six dimensions. For this study, Andrade et al.’s (2012) questionnaire was employed with modifications drawn from the ART-Q scale. Items were selected to assess the relevant learning outcomes and student engagement variables, and the wording of the questions was modified to refer to ShareFlow specifically (as shown in Table 6.5). Table 6.5 shows the students’ responses to the selected items in the dimensions of engagement; learning; student interaction; and technology. In the dimensions of engagement and learning, students scored the items on a 1-5 Likert scale of *Always* – 5, *Almost always* – 4, *Occasionally* – 3, *Almost never* – 2, *Never* – 1. In the dimensions of student interaction and technology, students scored the items on a 1-5 Likert scale of: *Strongly agree* – 5, *Agree* – 4, *Neutral* – 3, *Disagree* – 2, *Strongly disagree* – 1.
Table 6.5 Student evaluation of ShareFlow

<table>
<thead>
<tr>
<th>Dimension: Engagement</th>
<th>Likert response (n=39)</th>
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<tbody>
<tr>
<td></td>
<td>Never</td>
</tr>
<tr>
<td>I feel more involved in class because we use ShareFlow</td>
<td>-</td>
</tr>
<tr>
<td>Reading, thinking on (and responding) to posts and feedback improves my attention</td>
<td>-</td>
</tr>
<tr>
<td>ShareFlow reduces my anxiety in understanding NOS content</td>
<td>-</td>
</tr>
<tr>
<td>The quality of the ShareFlow posts increases my level of engagement</td>
<td>-</td>
</tr>
<tr>
<td>Provides a forum for sharing ideas virtually</td>
<td>-</td>
</tr>
<tr>
<td>Fosters discussion of ideas face-face</td>
<td>-</td>
</tr>
<tr>
<td>Allows access beyond class time</td>
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</table>

<table>
<thead>
<tr>
<th>Dimension: Learning</th>
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<tbody>
<tr>
<td>ShareFlow facilitates explicit teaching and learning about NOS</td>
</tr>
<tr>
<td>ShareFlow makes me aware of prior knowledge of NOS ideas</td>
</tr>
<tr>
<td>The use of ShareFlow contributed to my understanding of NOS</td>
</tr>
<tr>
<td>Viewing posts and feedback helps me assess (ongoing) my own understanding of NOS</td>
</tr>
<tr>
<td>It allows the ideas of others to be seen</td>
</tr>
<tr>
<td>It allows for the improvement of ideas about NOS</td>
</tr>
<tr>
<td>Allows for the collective building of ideas about NOS</td>
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</table>

<table>
<thead>
<tr>
<th>Dimension: Student interaction</th>
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<tbody>
<tr>
<td>ShareFlow helps me communicate better with other classmates in this course</td>
</tr>
<tr>
<td>ShareFlow helps me communicate better with the lecturer in this course</td>
</tr>
<tr>
<td>I learn from the feedback/replies to others’ posts</td>
</tr>
<tr>
<td>I learn from the feedback/replies to my posts</td>
</tr>
<tr>
<td>It encourages a stronger collegiality within the class</td>
</tr>
<tr>
<td>It supports group work, and discussions</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Dimension: Technology</th>
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</thead>
<tbody>
<tr>
<td>The ShareFlow interface is easy to use</td>
</tr>
<tr>
<td>I can see my posts and the posts of others quickly</td>
</tr>
<tr>
<td>The technology is not intrusive or disruptive</td>
</tr>
<tr>
<td>The technology is a hindrance to interaction</td>
</tr>
<tr>
<td>The technology increases the possibility of becoming side-tracked or distracted</td>
</tr>
<tr>
<td>This is a type of use of technology I would want to use in my own teaching practice</td>
</tr>
</tbody>
</table>
Analysis of the responses to the Likert items shows that when thinking about the impact of ShareFlow on their engagement, over 80% of the students felt they were always or almost always involved in class, less anxious about NOS and more engaged. More than 80% considered that ShareFlow always/almost always improved their attention, and fostered discussion.

In terms of the items evaluating learning, the students unanimously agreed that ShareFlow allowed them to see the ideas of others and almost always/always agreed with each of the other items, strongly suggesting a perception that ShareFlow benefited their learning. Since research on NOS has clearly indicated that it requires explicit instruction, it is most interesting to note that 92% of the students agreed/strongly agreed that ShareFlow facilitated explicit teaching and learning about NOS.

Regarding the dimension of student interaction, more than 80% of the students agreed/strongly agreed that ShareFlow allowed them to communicate better with their peers and with the lecturer, that they learned about NOS from the replies of others to their posts, and even more so from the feedback and replies to their own posts. It is interesting to note that 77% agreed/strongly agreed that ShareFlow supported group work and discussions.

The technology interface itself was considered to be easy to use, especially its quick refresh rate that enabled the posts of others to appear on screen almost instantly. 74% were neutral when responding to the item that it increased the possibility of becoming side tracked or distracted. The wording of this question, however, asked students to comment on the possibility of becoming distracted, rather than to report on whether they were/were not distracted themselves. Of particular interest concerning the technology is that 90% of the students did not consider technology to be a hindrance to interaction.

All of the students opted to consider using this type of technology in their own teaching practice. This is significant in terms of their willingness to adopt the technology and does positively reflect their engagement with it.

Regarding the mean scores for each item, it has been suggested that a 5- or 7-point scale may produce slightly higher mean scores relative to the highest possible attainable score, compared to those produced from a 10-point scale (Dawes, 2008). Nonetheless, these means indicate strong satisfaction with ShareFlow as a tool to facilitate engagement and learning, and in that respect they parallel other studies.

**Discussion**

Review of research studies over the last 40 years suggests that the most effective approaches to developing a robust understanding of NOS are those that have a substantial reflective component (e.g., Abd-El-Khalick & Akerson, 2004; Akerson & Donnelly, 2010; Baird, Fensham, Gunstone, & White, 1991; Capps & Crawford, 2013; Heap, 2007; Lotter et al., 2009; Scharmann et al., 2005; Schwartz et
This research study has reported on the use of Web 2.0 technology, specifically the ShareFlow platform, as a means to intentionally maximise opportunities for reflection on NOS.

As noted earlier, the course was structured, as in standard teaching practice, for explicit teaching of NOS, providing opportunities for students to reflect upon, share and discuss ideas in conventional ways. However, in addition, ShareFlow was used to create a synchronous ‘virtual classroom’ on NOS in every session in order to significantly increase opportunities for students’ reflection and metacognition, assessment and negotiation of their ideas, and to provide space for effecting conceptual change in NOS ideas. ShareFlow addressed both the requirement for conceptual change and for the active construction of knowledge. It allowed for the initial level of each preservice teacher’s conceptual knowledge of NOS to be acknowledged, and provided repeated opportunities for reflection and the development of a more robust understanding of NOS – within the short timeframe available.

**ShareFlow to enhance feedback**

The ShareFlow platform provided ample opportunity for the students to give and receive feedback as their ideas about NOS developed. As discussed in the Findings section, Table 6.1 and Figure 6.1 both indicate an increase in the instances of feedback as posts on ShareFlow, particularly the feedback from students to students. Since student thinking was consistently visible, in the form of posts, it was possible for the teacher, or increasingly for the students themselves, to provide information to fill the gap between what was understood and what was aimed to be understood (Sadler, 1989). It is interesting to note that the students themselves increasingly adopted this role, while the teacher to student feedback decreased slightly towards the end of the course. This is a consequence of the limited time available in each session for a teacher to give such feedback. In effect, student feedback to other students increased the opportunity for feedback to students beyond what a teacher alone could provide. There were 39 possible sources of feedback rather than one teacher as the only source.

However, since all the posts were consistently monitored by the teacher, feedback from the teacher could always be given in a timely manner to address any misconceptions on NOS that became apparent in the posts, reinforce interesting contributions or to start a class discussion where appropriate. In this way, the teaching was visible to the students and the learning visible to the teacher (Hattie, 2009). Formative feedback was provided in a seamless, ongoing manner throughout each session.

The students’ evaluation of ShareFlow, as shown in Table 6.5 and discussed in the Findings section, shows a high mean score for each of the items in the dimensions of ‘Learning’ and ‘Student interaction’ that relate to active construction of knowledge, reflection and feedback. For example, 98% of students reported that viewing ShareFlow posts and feedback always/almost always helped
them assess (ongoing) their own understanding of NOS, with a mean of 4.48 for this item. Ninety two percent of the students identified that ShareFlow almost always/always facilitated explicit teaching and learning about NOS (mean 4.67). The evaluation data here reiterates that the feedback held instructional purposes for the students and provided information specifically related to the process of learning (Sadler, 1989). ShareFlow provided information to the students about their understanding of NOS and allowed for repeated opportunities to give and receive this kind of feedback.

Terhart (2011) contends that feedback may also reduce the gap between what is understood and what is aimed to be understood through affective processes such as increased engagement. The positive mean scores in the ‘Engagement’ dimension of the ShareFlow evaluation in Table 6.5 indicate that ShareFlow did address affective processes. For example, 97% of the students reported that the quality of the ShareFlow posts almost always/always increased their level of engagement, and 90% identified that reading, thinking on (and responding) to posts and feedback almost always/always improved their attention.

These positive findings are consistent with other studies on the use of audience response technology (ART) such as clickers and other computer assisted feedback (CAF). Previous studies have found most consistent and positive results with respect to classroom engagement. For example, several studies indicate that students view ART or CAF as a positive influence on their attention, interest, or involvement during class (Andrade et al., 2012; Liu, Wang, Liang, Chan, Ko, & Yang, 2003; Nicol & Boyle, 2003; Rice & Bunz, 2006). As found in this study, the positive impact on student learning is also documented in other studies (e.g., Cochrane, 2011, 2013; Kay & LeSage, 2009).

**ShareFlow to enhance community of practice**

Students posting their own ideas, commenting on the ideas of others, receiving and giving feedback, all contributed to developing the community of practice (COP) of these students. Quantitative analysis of the data, presented in Table 6.2 and Figure 6.2, shows the increasing participation in a community of practice. However, it should be noted that while the posting of a comment shows participation, it does not necessarily, by itself, indicate learning in the sense of developing a more contemporary understanding about NOS. Hence, Table 6.2, showing increasing participation, does not necessarily indicate increasing understanding. However, analysis of all the student posts on ShareFlow over the duration of the course certainly does indicate increasing understanding, as illustrated, for example, by the student posts quoted in the sections on ‘Feedback’ and ‘Collective cognitive responsibility’. So, too, does a comparison of pre- and post-views on NOS using VNOS-C questionnaire, as shown in Table 6.3. Similarly, a shift in understanding of NOS views is clearly evident in the illustrative student quotations in Table 6.4.

In a similar study, Junco, Heiberger, and Loken (2011) found that Semester GPAs, as well as student
engagement scores (from the National Survey of Student Engagement), were significantly higher for a
group of students \( n=70 \) who used Twitter than for the control group \( n=55 \) who did not. They
concluded that Twitter promoted active learning, provided an avenue for prompt feedback and
maximised time on task.

Quantitative and qualitative analysis of the ShareFlow postings indicates that students were not
passive recipients of information from transmission style lectures on NOS, but rather were co-creators
of knowledge through the exchange of ideas and experiences. ShareFlow provided multiple
opportunities for student engagement and self-directed learning while it facilitated the sharing of
content and promoted collaborative learning (Dede, 2008; McLoughlin & Lee, 2010). The increase in
student to student feedback, as discussed, also evidences the significant levels of collaborative
learning. This essentially allowed the teacher to relinquish the role of sole engineer of the learning
process and turn epistemic agency over to the students (Scardamalia, 2002).

The COP view of learning is that learning is not exclusively a mental act but rather is a social act, set
in a participatory social context and dependent upon interaction among people and their tools and
technologies (Gee, 1999; Lave, 1996; Rogoff et al., 1995). Table 6.5 shows that 80% or more of the
students agreed/strongly agreed that ShareFlow increased their interaction with people, in every
category of interaction: with classmates, with lecturer, in learning from others, by encouraging
collegiality and by supporting group discussions. In terms of their interaction with the
tools/technologies, the quality of ShareFlow as a Web 2.0 interface, which according to Kling et al.
(2003) is critical, was positive. Both the social and the technological nodes became part of the
teaching and learning system that enhanced a community of practice and fostered the learning of
NOS.

**ShareFlow to enhance collective cognitive responsibility**

Scardamalia and Bereiter’s (2003a) knowledge forum and knowledge building pedagogy extends this
pedagogy of COP further by proposing that individuals within a knowledge building community are
not just sharing knowledge, but are using their own and the ideas of others to construct a collective
understanding and, yet further, to create knowledge. The data analysis of ShareFlow postings shows
repeated examples of students using and building on each other’s ideas - and in doing so, developing a
collective understanding. For example, the string of posts quoted in the section headed ‘Collective
cognitive responsibility’ shows students developing their understanding on the nature of observation
in science. Analysis of all the ShareFlow posts consistently demonstrated sociocognitive and
 technological determinants of knowledge building (Scardamalia, 2002), such as treating ideas as
improvable, assuming epistemic agency, producing ideas of value to each other and sharing
responsibility for overall knowledge advancement of the community.
Second, in their ShareFlow evaluation (Table 6.5), items related to knowledge building rate highly; all students reported that ShareFlow always enabled the ideas of others to be seen. No other item in the evaluation was 100% strongly agree. The items relating to the improvement of ideas about NOS and the collective building of ideas respectively drew 97% and 95% Always/ Almost always responses.

Scardamalia and Bereiter (2006) propose six themes that underlie a shift from treating students as learners, to treating them as members of a knowledge building community. These themes are knowledge advancement as a community rather than individual achievement; knowledge advancement as idea improvement rather than as progress toward true or warranted belief; knowledge of in contrast to knowledge about; discourse as collaborative problem solving rather than as argumentation; constructive use of authoritative information; and understanding as emergent. These themes fall largely outside the scope of this chapter, although knowledge of in contrast to knowledge about is discussed as it relates strongly to preservice teacher education and the translation of NOS understandings into practice.

Whereas knowledge about is approximately equivalent to declarative knowledge, knowledge of is much richer. Knowledge about NOS, expressed in a declarative or even explanatory way, has limited usefulness and applicability (Ford, 2008; van Dijk, 2011). In contrast, knowledge of enables teachers to use their NOS knowledge so that it becomes functional; functional for teachers in terms of devising learning experiences for their students and functional in due course for those students in enabling them to use their NOS knowledge to address socioscientific issues, judge the quality of scientific arguments, decide whose expertise to trust, understand where verifiable information ends and value judgements begin, and so on (Allchin, 2011). For example, it is not as important to demonstrate that one knows that science is influenced by social and cultural milieu, as it is to be able to recognise how these influences can be manifest in any particular case encountered in daily life (Rudge & Howe, 2009). Allchin (2011) suggests that as a foundational principle, the goal of an understanding of NOS should be “interpreting the reliability of scientific claims in personal and public decision making” (p. 521).

For the preservice teachers, knowledge about NOS needs to be translated into a depth of knowledge of that allows teachers to know why, when, how and what NOS to teach for functional and critical scientific literacy. This depth of knowledge is difficult to teach in the short duration of the preservice teacher education programme. So, the use of ShareFlow was intended to keep NOS very visible, as a subtext running through each session or a parallel virtual class session on NOS running concurrently within each face-to-face session. It addressed the need for preservice teachers to recognise the plethora of opportunities any science session has to teach NOS. As an ongoing subtext, it allowed them to develop knowledge of rather than only knowledge about NOS.
Korthagen and Kessels (1999) argue that one of the central problems with teacher education is that the theoretical body of knowledge taught in preservice teacher education is not the kind of knowledge that teachers draw upon while teaching. They contend that, for the most part, teacher education programmes emphasise knowledge that is abstract, systematised, and independent of specific instructional settings. Unfortunately, this kind of knowledge does not readily come to mind during classroom practice (Hewitt, Pedretti, Bencze, Vaillancourt, & Yoon, 2003). In practice, teachers are continually in situations in which they need to recognise teachable moments and teach to such affordances. Analysis of the ShareFlow posts has shown that using ShareFlow provided an ongoing platform for this community of learners to individually recognise and jointly share the opportunities for NOS teachable moments they noticed in the sessions (and hopefully, in the future, in their own teaching practice). For example, the string of posts quoted in the section ‘Enhancing feedback’ shows the students seeing the teachable moments for obesity, diabetes, food labelling and addressing global food shortage while they were investigating the crunchiness of potato chips. The breadth of these posts on teachable moments exceeded any contribution and discussion that has been provided by the lecturer alone, in any of her previous teaching programs without ShareFlow. Furthermore, these NOS teachable moments remained as a growing repository of ‘opportunities to teach NOS in your own class’.

Concluding Thoughts

In the recent past, there has been a trend to use technology to support traditional modes of teaching, such as improving the quality of lecture presentations, using PowerPoint, and providing access to digital resources and libraries. Whilst of value, these innovations have not transformed the teacher-learner relationships. More than any previous educational technology, Web 2.0 has the potential to support such a transformation by allowing learners to be active participants and co-creators of knowledge, rather than passive recipients of knowledge and skills.

This research study extended students’ use of Web 2.0 in their personal and social lives out of school (e.g., social networking) into the tertiary learning environment. It was found that ShareFlow, as a Web 2.0 platform, enhanced the community of practice among the students and fostered learning of NOS through increasing participation in this community. The emphasis was shifted away from the individual student’s acquisition of a deeper understanding of NOS to a collective cognitive responsibility within the class – a joint enterprise in which class members made contributions and recognised NOS ideas as being improvable objects. ShareFlow provided a platform which made visible the thoughts of students, and allowed multiple and repeated opportunities for reflection and for repeated and persistent opportunities for feedback on ideas about NOS. This feedback was multidirectional: from the student to the lecturer, from the lecturer to the students, and from the students to one another.
ShareFlow created a gateway to communication and collaboration in a learning space that allowed students to construct knowledge online while continuing to learn through other active engagement such as class or group discussions and the hands-on activities and investigations that are an integral part of most science courses. ShareFlow acted as an intervention tool by behaving as a “highly participative” mediator (Mason & Rennie, 2010, p. 99). Therefore, this medium gave students an opportunity to actively construct knowledge, in this instance about NOS, through engagement.

This research study indicates the positive impact of the use of Web 2.0 technology, in this case to develop understanding of and about NOS, but with implications that are much broader in terms of the use of Web 2.0 technology in tertiary learning environments.
Chapter 7:
Towards More Effective NOS Teaching: Developing Pedagogical Content Knowledge, Enhancing Motivation and Building Self-efficacy Beliefs Through Peer Teaching and Microteaching

Introduction
The nature of science as a requirement of scientific literacy is well argued in the research literature (Hodson, 2008; Matthews, 2012; Tytler, 2007) and is now clearly established as an important learning objective of science curricula in many countries (Abd-El-Khalick, Bell, & Lederman, 1998; Matthews, 2012). Indeed, the importance given to NOS is such that “improving students’ and teachers’ understanding of NOS has shifted from a desirable goal to being a central one for achieving scientific literacy” (Dagher & BouJaoude, 2005, p. 378). Ensuring students have an understanding of NOS has been one of the most consistent and central elements of science education reform over the last 20 years.

There is widespread consensus that effective teachers are the critical factor for student learning (Darling-Hammond, 2009; Hanuscin et al., 2011) and that teachers’ beliefs and knowledge may be regarded as a crucial leverage point to effect a change in the classroom. For effective science learning, teachers must hold views of NOS that are sufficiently extensive and critical to determine what NOS to teach at each level, in order that all students leave school with:

- robust knowledge about the nature of scientific inquiry and theory building, an understanding of the role and status of scientific knowledge, an ability to understand and use the language of science appropriately and effectively, the capacity to analyze, synthesize, and evaluate knowledge claims, some insight into the sociocultural, economic and political factors that impact the priorities and conduct of science and a developing capacity to deal with the moral-ethical issues that attend some scientific and technological developments. (Hodson, 2009a, p. 18)

However, studies have also indicated that, even if a teacher does have a sound understanding of NOS, there is not necessarily a direct translation of this understanding into practice (e.g. Hanuscin et al., 2011; Hipkins et al., 2005; Schwartz & Lederman, 2002). Thus, the position faced by science teacher educators is a challenging one.

To add to the body of knowledge concerning the translation of NOS understandings into practice, the intervention undertaken in the present study was twofold. The first was to integrate into the preservice teacher education course those curricular and instructional elements evidenced by research literature as being effective in developing more robust NOS conceptions among preservice teachers. These
elements include the use of: explicit NOS instruction; decontextualised NOS activities; contextualised embedded NOS instruction; historical and contemporary case studies; metacognitive learning strategies; a conceptual-change framework; and repeated opportunities for ongoing reflection (e.g., Wahbeh & Abd-El-Khalick, 2014; Bell et al., 2000).

The second was to develop the pedagogical content knowledge (Shulman, 1987) required for translation of selected dimensions of NOS into practice by incorporating into the course NOS-inclusive lesson planning, peer teaching, and microteaching. It is the effectiveness of peer teaching and microteaching which is reported in this chapter.

Background

Translation of NOS understandings into practice

The translation of a teacher’s conception of NOS into classroom activities and, thereby, into students’ understanding of NOS is a complex process. Previous research has reported a variety of personal and contextual factors as mediating or constraining the translation. These factors include: pressure to cover content (Hodson, 1993; Schwartz & Lederman, 2002); constraints of the curriculum (Hodson, 2011); other curriculum imperatives (Hipkins et al., 2005); classroom management and organizational issues (Abd-El-Khalick, et al., 1998; Hodson 1993); teachers’ perceptions of their students’ interest in, and ability to internalise, ideas about NOS (Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Zembylas, 1998); teachers’ beliefs about the importance of their students’ learning about NOS (Lederman, 1999; Lederman, Abd-El-Khalick, & Bell, 2001); lack of availability of instructional materials, teaching and learning resources, and assessments related to NOS (Hanuscin et al., 2011); and both teachers’ and students’ subject matter knowledge (Akerson et al., 2010; Schwartz & Lederman, 2002).

It is posited in this research study that some of these factors could be addressed, in part, in preservice teacher education if preservice teachers were better equipped in their planning to teach NOS, had a deeper pedagogical content knowledge (PCK) of NOS, and had more opportunity to practise teaching NOS during their preservice teacher education programs.

What NOS to teach?

Research studies have indicated that these mediating variables are exacerbated by the depth and breadth of teachers’ NOS understandings (Abd-El-Khalick, 2005; Akerson et al., 2010; Schwartz & Lederman, 2002). Much of the research in science teacher education reports that the challenge for preservice teacher educators is compounded further, in that the majority of students entering elementary teacher education programs have limited science subject knowledge and a less-than-enthusiastic attitude towards teaching science (e.g., Appleton & Kindt 2002; Garbett, 2011; Preece,
Postlethwaite, Skinner, & Simpson, 2004), and lack an understanding of NOS (e.g., Akerson, Morrison, & McDuffie, 2006; Dogan & Abd-El-Khalick, 2008; Tsai, 2002). These problems are intensified by the insufficient time available in most preservice teacher education programs to address these issues, and the limited opportunities for professional development once teaching.

In New Zealand, the current science curriculum does reflect the strong international emphasis on NOS, describing it as “the overarching, unifying strand” (Ministry of Education, 2007a, p. 9). The NOS strand is required learning for all students up to year 10 (approximately 15 years of age). The other strands (essentially biology, physics, chemistry, geology, and astronomy) “provide contexts for learning” (p. 9). This imperative of NOS as a curriculum requirement serves as a very strong driver for prioritising NOS in teacher education courses, and as an external motivator for teachers to prioritise NOS in their science teaching.

However, although NOS is given a prominent place in the New Zealand curriculum document, the document itself provides a minimal curriculum framework rather than a comprehensive guide with specific explanations of what and how to teach, and when. The curriculum provides broad achievement aims in each strand. For example, in the NOS strand the achievement aim for the sub-strand “understanding about science” is that students will “Learn about science as a knowledge system: the features of scientific knowledge and the processes by which it is developed; and learn about the ways in which the work of scientists interacts with society” (Ministry of Education, 2007b, para. 1). Achievement aims are broken into achievement objectives that describe, for each strand, the knowledge, learning processes, and skills relative to eight levels of learning, from school entry at 5 to 6 years of age to leaving school at 16 to 18 years of age. For example, at Level 1 the achievement objective for the NOS strand “understanding about science” is that students will “Appreciate that scientists ask questions about our world that lead to investigations and that open-mindedness is important because there may be more than one explanation” (Ministry of Education, 2007a, p. 45). No further detail is provided in the curriculum as to how to meet these NOS aims and objectives. It is a broad framework rather than a detailed plan.

Every school has the mandate to develop its own curriculum and teaching programs from the curriculum document as best suits the particular needs of the students in each school. Teachers have to interpret the document and generate specific teaching, learning, and assessment materials in every learning area, including science, and including NOS. The leanness of the curriculum is both a freedom and a hurdle. It presents an enviable opportunity for schools and teachers to design an appropriate teaching/learning programme for its students, but it also leaves teachers without the highly specific guidance which they (especially beginning teachers) may need – particularly within an unfamiliar area such as NOS.
It is not easy to identify unequivocally the contemporary views of NOS appropriate for preservice teacher education, or for school learners and science teachers. There is a broad range in the level of breadth, depth, and sophistication at which NOS can be explored, and the literature reveals no consensus or standard definition of the precise meaning of NOS. In the science education course in this research study, the preservice teachers were introduced, among others, to: curriculum requirements for NOS instruction (Ministry of Education, 2007a, 2007b); Lederman’s (1992) NOS seven tenets; Clough’s (2007) challenge to reframe these tenets as questions; McComas and Olson’s (1998) review of science curricula and reform documents; Osborne et al.’s, (2003) NOS themes; Matthew’s (2012) features of NOS; and Hodson’s (2011) call for broader goals for NOS as situated within education for critical scientific literacy to build informed and responsible citizenship. Each of these represents a different orientation to teaching NOS.

The particular orientation taken by teachers to teaching NOS will be profoundly influenced by what motivates them. If they are motivated by curriculum compliance they may teach very differently than if they are motivated, for example, by a belief that the purpose of education is preparation for citizenship and active engagement with socioscientific issues at personal, local, regional, and global levels.

**The need for pedagogical content knowledge**

Effective teachers are those who are skilled in transforming their own subject knowledge – in this research study that is knowledge about NOS – into sequences of varied learning experiences that acknowledge what is known to be already familiar to learners, to help learners construct personal knowledge and accomplish shifts towards the target knowledge represented in curriculum documents (Taber, 2010). Shulman (1987) first used the term pedagogical content knowledge (PCK) to describe this interweaving of pedagogical knowledge (knowledge of teaching and learning methods) and subject matter knowledge necessary for good disciplinary teaching:

> Pedagogical content knowledge identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction. (Shulman, 1987, p. 4)

PCK, according to Shulman (1986), is what makes possible the transformation of disciplinary content into forms that are accessible and attainable by students. It represents the synthesis of teachers’ knowledge of both subject matter and pedagogy, an amalgam of knowledge of content and knowledge of practice brought together in a particular way through the specialist teacher’s expertise (1986) and is “uniquely the province of teachers” (1987, p. 8). Shulman (1987) posited that the development of teacher knowledge involves a dramatic shift in teacher thinking from a professional understanding of science content to an awareness of new ways in which topics, problems, issues, and subject matter
content can be represented, organized, and adapted to engage students in learning science. It is the crucial point at which teachers diverge from content specialists, in this case from scientists. It moves the teacher:

from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped.

(Shulman, 1987, p. 13)

In science education, subject matter includes understandings about NOS. Therefore, according to Shulman’s framework, an effective teacher must have not only a firm understanding and knowledge of NOS, but also knowledge of effective pedagogical practices relevant to NOS. Within Shulman’s framework, it follows that possessing a robust understanding of NOS is a necessary but insufficient condition for effective NOS teaching (e.g., Bell et al., 2011) – just as holding extensive substantive knowledge will not necessarily ensure effective teaching of science content. What is needed is PCK of NOS in addition to content knowledge of NOS (Hanuscin et al., 2011).

Grossman (1990) elaborated Shulman’s (1986) theorising to emphasise four general areas of teacher knowledge: subject matter knowledge, general pedagogical knowledge, knowledge of context, and pedagogical content knowledge. Grossman defined pedagogical content knowledge as comprising four components: knowledge and beliefs about the purposes and goals for teaching science, knowledge of students’ understanding of science, knowledge of science curricula and curricular resources, and knowledge of representations and instructional strategies.

Other scholars have developed Shulman’s model, specifically in relation to the teaching of science (including Abell, 2008; Appleton, 2006; Gudmundsdottir, 2013; Hashweh, 2005; Magnusson et al., 1999). For example, Magnusson, Krajcik, and Borko (1999) have extended Grossman’s (1990) model with two modifications: conception of purposes has been changed to orientation toward science teaching, and knowledge of assessment has been added as a component of PCK. Thus, they define PCK as consisting of five components: (1) knowledge of curriculum, (2) knowledge of students’ understanding of science, (3) knowledge of representations and instructional strategies, (4) knowledge of assessment, and (5) teacher orientation for science teaching. They posit that orientation to teaching science is central to PCK as the lens through which all components of PCK are understood, interpreted, and integrated, resulting in a unique form of knowledge held by teachers. It should be noted that all five components of the Magnusson et al. (1999) model are influenced by teacher subject matter knowledge and the specific context in which teaching takes place. This model, with its inclusion of assessment and orientation, was used in this research study to inform and to analyse student teacher lesson planning for NOS.

Orientation is described in Magnusson’s model as “the knowledge and beliefs possessed by teachers
about the purposes and goals for teaching science at a particular grade level” (Magnusson et al., 1999, p. 97). Teacher orientation acts as a ‘conceptual map’ guiding decisions about learning objectives, implementation of curricular materials, and evaluation of students’ learning (Magnusson et al., 1999). It fuels the intentions and abilities to merge subject knowledge and pedagogical knowledge into PCK in the classroom (Schwartz & Lederman, 2002).

Knowledge of assessment consists of (a) knowledge of the dimensions of science learning important to assess and (b) knowledge of assessment strategies and methods through which students’ learning can be assessed (Magnusson et al., 1999). Methods of effective assessment include informal, formative, and summative evaluations implemented to reveal students’ understanding of scientific concepts.

PCK has been interpreted and researched in many and varied ways at a range of education levels (Gess-Newsome & Lederman, 1999). For example, one approach to making PCK concrete for science teachers is that of the Content Representation (CoRe) and Pedagogical and Professional experience Repertoires (PaP-eRs), developed by a team of science education researchers at Monash University (Loughran, Mulhall, & Berry, 2004; Loughran et al., 2006). Subsequent studies on use of the CoRe and PaP-eRs approach with preservice and inservice teachers to make PCK explicit indicate that participants frame their knowledge of teaching in new ways as a consequence. Wallace and Loughran (2012) contend that:

PCK offers a lens into the complexity of science teachers’ professional knowledge in ways that draw attention not only to teacher learning, but also to how that learning might be recognised in, and influence the development of, practice. (p. 298)

PCK offers scope to address some of the factors that mitigate the translation of NOS into practice and was used in the current research study to analyse the preservice teachers’ lesson planning, which was a central and assessed component of the course.

The need for motivation and self-efficacy

Common to all learning theories, such as constructivism, cognitive constructivism, social constructivism, cognitivism, situated cognition, connectivism, navigationism, and so on, is that it is necessary for the student to retrieve their pre-existing knowledge and beliefs, relate them to what is currently being presented, and modify their knowledge and beliefs if required (e.g., Driver & Oldham, 1986; Kop & Hill, 2008). This reconstruction of meaning requires the learner to make an effort. Therefore, it follows that motivation is also required because students will not make that effort unless they are motivated to do so. Hence, motivation is a necessary prerequisite and co-requisite for learning and may be a key factor in determining the direction and extent of conceptual change (Pintrich, Marx, & Boyle, 1993), including conceptual change on views of NOS upon which this course was based. Of
course, beyond being motivated to learn about NOS, preservice teachers also need to be motivated to teach NOS.

In addition to motivation, self-efficacy is also required for teaching. Bandura (1977) proposed the concept of self-efficacy as a theory of behavioural change. The self-efficacy of an individual refers to that person’s judgments about how well they can “organise and execute courses of action required to deal with prospective situations that contain many ambiguous, unpredictable and often stressful, elements” (Bandura, 1981, pp. 200–201). It therefore represents an individual’s belief about his/her ability to successfully execute a course of action in a difficult or challenging situation. Self-efficacy is, therefore, considered an accurate predictor of performance; people with low self-efficacy about an activity will tend to avoid that activity, whereas people with high self-efficacy will make vigorous and persistent efforts and will be more likely to complete the task successfully (Palmer, 2006).

Concerning the teaching of NOS, potentially a difficult or challenging situation, those preservice teachers who have high self-efficacy concerning NOS teaching are more likely to translate their NOS understandings into practice than those preservice teachers with low self-efficacy concerning NOS teaching. Clearly, a preservice teacher education course that develops this self-efficacy is more likely to effect translation into practice. Palmer (2006) reports that many preservice primary teachers initially have a low self-efficacy, or belief in their ability to teach science, but well-designed science education courses can produce significant positive changes in efficacy beliefs.

Bandura (1977) described two critical components of self-efficacy: the first is the ‘response-outcome expectancy’, or the belief that the performance of the behaviour will have a desirable outcome; the second is ‘efficacy expectation’, which represents the belief in one’s ability to successfully perform the behaviour. Bandura (1981) emphasised that self-efficacy is highly context dependent, so a person may have a high self-efficacy with respect to one task but a low self-efficacy for another. The current research study was predicated on the assumption that translation of NOS knowledge into effective classroom practice would be highly influenced by the preservice teachers’ own perceptions of their ability to teach NOS (efficacy expectations), as well as a belief that their teaching strategies would be effective (response-outcome expectancies).

In later work, Bandura (1997) identified four principal sources of efficacy expectation: mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states (Bandura, 1997). The most powerful of these are mastery experiences, which are previous successes in dealing with a particular challenge. A strong sense of efficacy is developed through repeated successes in situations that require some perseverance in overcoming hindrances, and thus resilience is developed that enables rebound from occasional failures. For this reason, peer teaching and microteaching were used in the course, with the intention of providing mastery experiences, along with each of the other
three principal sources, for developing self-efficacy.

**Use of peer teaching and microteaching**

Microteaching can be described as a teaching situation that has been reduced in scope or simplified in some systematic way, involving “teaching for a short period of time, normally focusing on one particular aspect of a lesson or teaching technique” (Morrison, 2010, p. 19). It is frequently used in preservice teacher education courses, where preservice teachers teach a lesson to their peers, or others, as a way of providing a structured teaching experience and orienting student teachers to specific aspects of the teaching role (Amobi, 2005).

Microteaching is referred to in the literature by a variety of alternative terms such as peer mentoring, peer learning, peer tutoring, peer coaching, peer-led team learning, and collaborative learning (Topping, 2005), with these terms at times being used interchangeably. In this research study, peer teaching is used to describe the student teachers teaching each other in small groups during the laboratory-based tutorial sessions of the course. Microteaching is used to describe the student teachers teaching small groups of children during the one-day per week in-school component of their course.

Various research reports indicate that micro/peer teaching has generally been found to be an effective way of helping preservice teachers learn about and reflect upon effective teaching practice (e.g., I’Anson, Rodrigues, & Wilson, 2003; Klinzing, 2002) and provides a worthwhile learning experience in a positive and enabling context (Fernández, 2010; Topping, 2005). Research on student perspectives has shown that students themselves find it useful (Amobi, 2005; Bell, 2007), particularly when coupled with constructive peer feedback. Significantly, Garbett (2011) has reported that peer teaching shifts “the organization and structure of the session away from teacher-centered sessions oriented towards modeling exemplary practice to situating learning in the act of teaching” (p. 737).

This research study examined the effectiveness of peer teaching and microteaching to develop preservice teachers’ planning and teaching for NOS. Both were viewed in the light of Magnuson’s model of PCK and Bandura’s model of self-efficacy.

**Research Design**

The participants in the study were a cohort of University graduates \(n=145\) enrolled as preservice primary school teachers in the one year Graduate Diploma of Teaching (Primary Specialisation). The two major goals of the course were to develop preservice teachers’ understanding of contemporary views about NOS, and their ability to translate these views into effective teaching practice during the course, with the view that this could later mediate translation into their own classrooms.

Based on an extensive body of literature regarding the development of contemporary views of NOS,
the course was structured as an explicit, reflective, metacognitive, content-embedded approach, undertaken from a ‘learning as conceptual change’ framework. The course aims to help preservice teachers develop deep understandings and critical views of NOS, their place in the curriculum and their implications for science teaching and learning. Their developing views were assessed over the duration of the program, but discussion of this development falls outside the scope of this chapter.

In order to examine the mediation of translation of contemporary NOS views into practice, lesson planning, peer teaching, and microteaching were core, and assessed, components of the course. These elements of the programme comprise the focus of this chapter.

The peer-teaching component of this course was carried out over a 5-week period, with each class being divided into working groups of five students. Each week one student in each group planned, taught, and assessed their peers’ understanding in a 30-minute lesson to their group. The peer-teaching sessions were embedded within the regular two-hour laboratory/workshop session. The context of their teaching was directly related to the overall context of the laboratory/workshop session. After each peer teaching session the students gave feedback to their peer teacher, who then used this feedback to inform their own written critical reflection on their teaching session. This self-evaluation, which was required to draw explicitly on comments on the feedback forms completed by their peers, was submitted alongside the lesson plan for assessment in the course.

The microteaching component of the course was undertaken by each of the preservice teachers in their school-based class, where they spent one day a week for the year. The task was to teach a science lesson to a group of at least three children, or the entire class if they preferred to do so. They were required to ascertain the children’s understanding, analyse their findings of the children’s understanding, plan and teach a lesson accordingly which addressed their findings, assess the children’s post-lesson understanding and then report on their assessment, planning, and teaching of three children. This report, along with their lesson plan, was submitted for assessment in the course.

Following the microteaching the preservice teachers completed a self-evaluation protocol, considering the lesson they taught in the light of NOS as the ‘overarching and unifying strand’. They were asked to critique the lesson they taught, analysing the learning about NOS that took place for their students and themselves, answering questions such as: What did you teach about NOS (explicitly and/or implicitly)? How did you teach it? What went well? Was there an aspect of your teaching that surprised you, or was more or less effective than you thought it would be? In what ways has this teaching increased or decreased your confidence and competence to teach NOS?

As motivation and self-efficacy impact upon translation into practice, the Science Teacher Efficacy Belief Instrument (STEBI-B), as developed and tested by Enochs and Riggs (1990) for use with preservice teachers, was modified to specifically address NOS teaching and was used as a repeated
measure with two of the classes \((n=74)\). STEBI-B includes 23 Likert-scaled statements relating to personal beliefs about teaching science, of which 14 were used in this research. Response categories were strongly agree, agree, uncertain, disagree, and strongly disagree.

The research design exists within a design-based research tradition that recognises the importance of context and the complexity of the variables that lie within the learning processes (Kelly et al., 2008). Thus the evaluative approach that has been used here does not claim to isolate variables in order to measure their impact. Indeed, such isolation is almost impossible to achieve without producing an unacceptable level of artificiality (Barab & Squire, 2004; Sorenson et al., 2012).

**Data Analysis**

Data sources to examine the use of peer teaching and microteaching as means to develop PCK and self-efficacy for translation of NOS into teaching were:

- Lesson plans for peer teaching
- Lesson plans for microteaching
- Self-evaluation of peer teaching informed by peer feedback
- Self-evaluation of microteaching session
- Science Teacher Efficacy Belief Instrument (STEBI-B)
- Pre- and post-surveys of student perceptions of the teaching and learning approaches most useful in developing NOS understanding

Codes for analysis of the peer teaching and microteaching lesson plans were based on Magnusson et al.’s (1999) PCK components: (a) knowledge of curriculum; (b) knowledge of students’ understanding of science; (c) knowledge of instructional strategies; (d) knowledge of assessment; (e) science teaching orientations.

Analyses for knowledge of the curriculum component focused on the extent to which teachers were successful in articulating curriculum NOS achievement aims, achievement objectives, and instructional outcomes in their lesson plans (alongside appropriately related contextual aims, objectives, and learning outcomes for the science content matter being covered). For example, “Were specific NOS achievement aims, achievement objectives and learning objectives included in the lesson plan? Did the learning objectives reflect informed understandings about the target NOS aspect(s)?”

Preservice teachers’ knowledge of their students’ understanding of NOS was assessed by looking for

\[12\] Achievement aims and objectives are selected directly from the curriculum documents. The learning outcomes draw from these but must be planned and written by the teacher, and specify what the students will be able to do as a result of the teaching and learning experience. Hence, the learning outcomes provide evidence of the teacher’s ability to plan.
the inclusion of appropriate diagnostic assessment approaches. The manner in which preservice teachers planned to address these assessment findings and the achievement aims, objectives, and learning outcomes in their instructional activities was used to analyse their knowledge of instructional strategies and representations. Further analysis of instructional strategies focused on whether the NOS instruction was ‘stand-alone’ or integrated within science content instruction: and if stand-alone, were the ideas addressed in the activities eventually linked to the science content of the teaching session? Evidence of the ways in which preservice teachers planned to assess student NOS understandings was also inspected. Evidence of science teaching orientations was also broadly examined, although not reported here.

NVivo qualitative research software was used to code the peer teaching and microteaching self-evaluations, using Magnusson et al.’s PCK components and also Bandura’s (1997) four principal sources of efficacy expectation as a framework: mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states. The preservice teachers’ self-evaluation of their peer teaching and their microteaching lessons were analysed using a constant, comparative approach (Glaser, 1965) of the content analysis of their transcripts. The statements were initially coded, using NVivo, according to the key words and phrases used by each of the student teachers. Following this initial stage, the statements were grouped according to the components of Magnusson et al.’s PCK framework, and Bandura’s four principal sources of efficacy expectation. This was an iterative process as the coded statements were then assigned to developing categories within the frameworks. The data sources were also manually coded to remove possible ambiguities and to clarify categorizations.

In the analysis of NOS in lesson plans and self-evaluations, Matthews’ (2012) view that “it is unrealistic to expect students, or trainee teachers, to become competent historians, sociologists or philosophers of science” (p. 21) was considered to be important. Rather, the focus was a realistic but robust understanding of key elements of NOS. This study was exploratory and interpretive in nature (Le Compte & Priessle 1993). Data collection was continuous and spanned the duration of the study.

Findings

Lesson planning

Table 7.1 shows the analysis, using analytical codes developed from the theoretical framework of Magnusson et al.’s model of PCK, of the preservice teachers’ lesson plans for peer teaching their group of five students.
Table 7.1 Analysis of lesson plans for peer teaching

(n = 145)

<table>
<thead>
<tr>
<th>Knowledge of curriculum – science content and NOS</th>
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<tbody>
<tr>
<td>Appropriate Achievement Aims - for science content</td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
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<td>93</td>
<td>141</td>
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<tr>
<td>Appropriate Achievement Obj. - for NOS</td>
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<tbody>
<tr>
<td>No NOS related diagnostic assessment</td>
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<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Limited NOS related diagnostic assessment</td>
<td>97</td>
<td>67</td>
<td>18</td>
<td>12</td>
<td>30</td>
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<tr>
<td>Informative NOS related diagnostic assessment</td>
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<tr>
<td>Informative science content related diagnostic assessment</td>
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<tr>
<th>Knowledge of representations and instructional strategies for NOS</th>
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<tbody>
<tr>
<td>Science content related only</td>
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<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Unrelated NOS instruction</td>
<td>57</td>
<td>39</td>
<td>13</td>
<td>9</td>
<td>53</td>
</tr>
<tr>
<td>Appropriate NOS related - decontextualised</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Appropriate NOS related - contextualised</td>
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<tr>
<th>Knowledge of assessment of NOS – formative and summative</th>
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<tbody>
<tr>
<td>No NOS related formative assessment</td>
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<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
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<td>NOS related formative assessment included</td>
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<td>88</td>
<td>18</td>
<td>12</td>
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<td>NOS related summative assessment included</td>
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<tr>
<td>Science-content related formative and summative</td>
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<tr>
<th>Teacher orientation for NOS teaching (n=88)</th>
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<tbody>
<tr>
<td>Curriculum compliance</td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
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<tr>
<td>Lederman’s tenets</td>
<td>17</td>
<td>12</td>
<td>25</td>
<td>17</td>
<td>32</td>
</tr>
<tr>
<td>Clough’s questions or Matthew’s features</td>
<td></td>
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<tr>
<td>Related to real-life context or SSIs</td>
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All lesson plans were examined for evidence that the preservice teachers planned to teach about NOS. It can be seen that almost all of the students were able to correctly establish and record appropriate science-content related achievement aims and objectives for their teaching session. These were taken directly from the relevant contextual strands of the New Zealand Curriculum. However, when looking at the inclusion of NOS, the figures were much lower for the achievement aims (61%) and achievement objectives (63%). This was largely due to these being omitted rather than inaccuracies.

13 If the AA or AO, which the student took directly from the curriculum, matched the topic they were teaching and the learning experiences they were planning, it was deemed to be ‘appropriate’.
This same discrepancy between science content focus and NOS focus can be seen in the diagnostic assessment, where 95% of the preservice teachers showed appropriate diagnostic assessment of their peers’ science content knowledge, but only 21% did the same for NOS knowledge. Almost all of the 89 (61%) of the preservice teachers who identified NOS aims and objectives also specified a targeted learning outcome for NOS, with 87 (60%) of them doing so.

The preservice teachers’ plans showed between three and seven learning experiences for the session. A learning experience was coded as a NOS-related representation or instructional strategy if its primary focus was NOS-related, or if it was a content-related learning experience but also had a strong NOS focus, as evidenced by the teachers’ recording of questions, points to note, discussion notes, and so forth. These NOS-related experiences were further coded as decontextualised or contextualised. A decontextualised activity would be akin to those described by Lederman and Abd-El-Khalick (1998) where generic activities, devoid of science content, are used to illustrate aspects of NOS. If the preservice teacher clearly showed in their planning that this activity was then related back to the science content, it was coded as ‘appropriate NOS instruction – contextualised’. This category also included any explicit NOS instruction embedded in the science content in the form of discussions or questions. It can be seen that over a third of the students (39%) included only science-content related representations and instructional strategies: that is, no NOS instruction or NOS-related representations or instructional activities were evident. Thirteen preservice teachers (9%) taught some NOS content, but it was not related in any way to their lesson; 37% used decontextualised activities, which they then related in some way to the science content of their lesson; 15% embedded the NOS questioning and discussion within the science content in an appropriate manner.

Very few students showed planning to assess NOS, either formatively (12%) or summatively (21%). In contrast, all but two students included formative and summative assessment of the science content they covered in their session.

Student teachers’ orientation to NOS was examined by determining whether the NOS focus aligned most closely with statements in the curriculum only, Lederman’s (1992) tenets of NOS, Clough’s (2007) challenge to reframe these tenets as questions, Matthew’s (2012) features of NOS, or any of the aforementioned approaches but embedded within a socioscientific or real life context (e.g., Hodson, 2011; Allchin 2013). Of the 88 preservice teachers who included NOS instruction, most were oriented to re-framing NOS as questions, or to Matthew’s (2012) features of NOS.

Table 7.2 shows the same analytical framework applied to analysis of the student teachers’ lesson plans for their microteaching of children in schools, which took place towards the end of the course.
The analysis of the microteaching lesson plans shows that all of the preservice teachers included NOS aims and objectives (as well as science content-related aims and objectives). A significant increase was also seen in the number who planned specific NOS-related learning outcomes, with 94% of the students including at least one NOS-related learning outcome.

Having established learning outcomes for NOS, over 90% of the preservice teachers assessed their students’ prior understanding of targeted aspect(s) of NOS. Furthermore, 91% showed specific instructional strategies or representations related to their intended NOS learning outcome. Slightly less

<table>
<thead>
<tr>
<th>Knowledge of curriculum – Science content and NOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate Achievement Aims - for science content</td>
<td>Appropriate Achievement Obj. - for science content</td>
</tr>
<tr>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>145</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge of students’ pre-lesson understanding of science – for science content and NOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No NOS related diagnostic assessment</td>
<td>Limited NOS related diagnostic assessment</td>
</tr>
<tr>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge of representations and instructional strategies for NOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Science content related only</td>
<td>Unrelated NOS instruction</td>
</tr>
<tr>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge of assessment of NOS – formative and summative</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No NOS related formative assessment</td>
<td>NOS related formative assessment included</td>
</tr>
<tr>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>89</td>
<td>61</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Teacher orientation for NOS teaching (n=88)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Curriculum compliance</td>
<td>Lederman’s tenets</td>
</tr>
<tr>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>
than half of the preservice teachers (40%) used decontextualised activities; slightly more (60%) embedded their NOS teaching within the science content.

Each of these aspects of planning shows a positive shift from the earlier peer teaching lesson planning. Shifts were also seen in the planning for formative and summative assessment of NOS. However, still only a little over a third (39%) of the preservice teachers indicated the use of formative assessment in their lesson planning, and slightly less than a third (29%) included summative assessment.

Regarding orientations to teaching, more preservice teachers planned to teach NOS within a context related to the students’ real life worlds or a socioscientific issue, a shift from 10% in the peer teaching to 47% in the microteaching. Real life contexts used by preservice teachers in their plans included floating and sinking in the school pool, changes of state in making iceblocks, forces in sliding down the school slide, physical and chemical change in the kitchen, and so on. Socioscientific issues in their plans included such topics as non-regulation of sunbeds, peer pressure to be tanned, cellphone towers in residential areas, dragnet fishing in the local harbour, fluoridation of town water supply, and mining in conservation areas.

**Self-evaluations**

In order to examine PCK and self-efficacy towards teaching NOS, the peer teachers’ self-evaluations of their peer teaching and microteaching lessons were analysed. Data from two classes of the total cohort were used for this analysis (n=74). The students’ identification numbers were their number within the total cohort (n=145). Table 7.3 shows the results of thematic analysis of the students’ self-evaluation of their teaching of their peers using both the PCK framework and the self-efficacy framework, together with some representative comments.
Table 7.3 Analysis of self-evaluation of peer teaching

<table>
<thead>
<tr>
<th>Theme – reflective statements made concerning:</th>
<th>No. &amp; % (n=74)</th>
<th>Illustrative comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of curriculum – as related to NOS</td>
<td>29 39</td>
<td>Three of my peers commented that they appreciated my explicit reference to the achievement aims and objectives in the curriculum. And it was great to actually have to plan a lesson and use the curriculum to do this. I am developing a better understanding of how it fits together. But I am struck by the enormity of interpretation and scope that goes hand-in-hand with the need for me to know the science content before I try to teach it. One peer commented that I needed to be more aware of the level of content required. He felt the lesson was too difficult for the age I was targeting. I agree. I find it hard to know which NOS teaching is suitable at different levels (PT, SE, S14).</td>
</tr>
<tr>
<td>Knowledge of students’ understanding of science – Science content and NOS</td>
<td>48 65</td>
<td>I realised that while I had a good handle on how to assess my peers’ prior understanding of the science content knowledge, it did not even occur to me to assess their prior understanding of my targeted NOS achievement objective (PT, SE, S56).</td>
</tr>
<tr>
<td>Knowledge of representations and instructional strategies for NOS</td>
<td>61 82</td>
<td>I repeated one of the NOS activities from earlier in the course – but I related it to the electricity activity we were doing. My peers’ feedback was positive on this and I can see how activities like this will be useful in prompting thought and discussion with my own students in the future (PT, SE, S137).</td>
</tr>
<tr>
<td>Knowledge of assessment of NOS</td>
<td>46 62</td>
<td>I realise that short of direct questioning, I don’t know how to assess NOS understanding (PT, SE, S92).</td>
</tr>
<tr>
<td>Teacher orientation for NOS teaching</td>
<td>42 57</td>
<td>Plate tectonics was a brilliant context for relating tentative modelling and scientists’ use of models back to earthquakes in Christchurch, volcanoes in Auckland and the risks of living on a plate boundary in New Zealand. One peer gave feedback, tongue in cheek, that he was going home to assemble a Civil Defence survival kit. All peers reported that they were more engaged because the lesson was made relevant (PT, SE, S25).</td>
</tr>
<tr>
<td>Mastery experiences</td>
<td>64 86</td>
<td>This has been a positive experience. I enjoyed the teaching (imperfect) and can see more clearly the strengths and weaknesses of my planning and teaching (PT, SE, S69).</td>
</tr>
<tr>
<td>Vicarious experiences</td>
<td>58 78</td>
<td>Last week I was a peer student. I am glad I was not first to teach as I learnt much from giving peer feedback as the student. I remember thinking as I was planning my teaching session, that if Sam could teach so well then perhaps so could I (PT, SE, S48).</td>
</tr>
<tr>
<td>Verbal persuasion</td>
<td>59 79</td>
<td>It was gratifying to receive positive feedback, and constructive ‘where to next’ feedback from my peers. Two months ago I had never given thought to the nature of science. One month ago, I felt the enormity of teaching science so differently than how I remember being taught. Now I find myself relishing the prospect (PT, SE, S145).</td>
</tr>
<tr>
<td>Physiological and affective states</td>
<td>52 70</td>
<td>I was impossibly nervous when I began. Feedback from my peers has boosted my confidence (PT, SE, S32).</td>
</tr>
</tbody>
</table>

To provide data on the preservice teachers’ PCK and self-efficacy later in the course, the preservice teachers’ self-evaluations of their microteaching session with children in schools were also analysed (Table 7.4). It is not appropriate to draw direct causal comparisons between the self-evaluation of peer
teaching mid-course (Table 7.3) and the self-evaluation of microteaching (Table 7.4) at the end of the course. The situations are different, there are too many variables and it is complex. However, there is some value in looking at overall patterns. It can be seen then, that more of the teachers included each of the PCK components in their reflective statements for microteaching than in the peer teaching self-evaluations. Similarly, in the peer teaching self-evaluations significant increases were evident in each of Bandura’s (1997) four dimensions of self-efficacy.

Table 7.4 Analysis of self-evaluation of microteaching

<table>
<thead>
<tr>
<th>Theme – reflective statements made concerning:</th>
<th>No. &amp; % (n=74)</th>
<th>Illustrative comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of curriculum – as related to NOS</td>
<td>72 97</td>
<td>It’s a real eye opener to see how using NOS as the lens to teach through totally shifts the focus from facts/content based to interesting, gritty, science in the real world. Even if I am just making pikel pets with 7-year-olds (MT, SE, S37).</td>
</tr>
<tr>
<td>Knowledge of students’ understanding of science – Science content and NOS</td>
<td>74 100</td>
<td>I used Kibble’s cards as a diagnostic assessment. I was totally surprised that the children really did select the cards which research indicates children have selected!!! Knowing the kinds of ideas I can anticipate will certainly make my teaching role easier – and more beneficial for the students. Even more interesting was to see that, with a bit of background reading, I could infuse NOS through the Kibble cards in terms of how science ideas regarding astronomy have changed over time – so 1,000 years ago the best astronomers in the world would have had different explanations than we have now (MT, SE, S128).</td>
</tr>
<tr>
<td>Knowledge of representations and instructional strategies for NOS</td>
<td>64 86</td>
<td>‘The Whole Picture’ activity14 was great to introduce students to the NOS features of the use of models, empirical basis, and inference. We continued discussion of these ideas during a session on plate tectonics and earthquakes in Christchurch15 (MT, SE, S112).</td>
</tr>
<tr>
<td>Knowledge of assessment of NOS</td>
<td>43 58</td>
<td>I tried to assess some NOS. I did diagnose prior understanding by getting the children to draw their image of a scientist. Throughout the teaching I brought up images of scientists working in the field of melanoma research and asked questions to disrupt their stereotypical views. We had a summative discussion, which included their image of scientists, at the end of the lesson, but I think this would need to be over a much longer period of time to be summative assessment (MT, SE, S83).</td>
</tr>
<tr>
<td>Teacher orientation for NOS teaching</td>
<td>59 79</td>
<td>I was blown away by the enthusiasm of the children. Before we wired up our simple circuits, we brainstormed all the different times they had used electricity before they arrived at school that day. After all the practical circuit building, I finished by reading a letter from my sponsor child in Tanzania and we discussed the day of a 9-year-old without electricity. Could have done with so much more time! (MT, SE, S61).</td>
</tr>
</tbody>
</table>

14 (Lederman & Abd-El-Khalick, 1998). This is one of a series of generic activities, devoid of science content and used to illustrate aspects of NOS.
15 The 2011 Christchurch earthquake is the second most destructive earthquake in New Zealand’s history. There have been over 11,000 aftershocks since with over 50 being above magnitude 5.
Before the science course I was negative and apprehensive about teaching science. My experience of science at school was that it was hard and boring. The first session on NOS blew me away – but also scared me witless. NOS was so not what I had in my mind concerning science. The peer teaching and microteaching have opened the floodgates. I can do this. I actually enjoy it and see the potential and immeasurable worth of teaching science to my students (MT, SE, S2).

When we did the peer teaching, it was with the sense of all having a go together – mistakes and all – and learnt a huge amount from seeing each other teaching NOS. I think all of us came out of that experience more confident to teach NOS (and science in general) (MT, SE, S110).

The NOS I taught in peer teaching was well received judging from the feedback from my peers. So I used the same NOS focus with the children in this lesson, and really didn’t need to change it much at all (MT, SE, S97).

“Self-belief does not necessarily ensure success, but self-disbelief assuredly spawns failure” (Bandura, 1997). I wrote this at the top of my lesson plan so it would be in sight in the lesson. This was my first go at teaching science to children, and with NOS as the underpinning strand, it feels a very different science than the little I remember from school days (MT, SE, S61).

### Self-efficacy survey

Table 7.5 shows the results of using the STEBI-B survey as a repeated measure to examine students’ perceived self-efficacy. The students rated each of the 14 items on a 5-point scale, where strongly agree was rated as 5 points, agree as 4, undecided as 3, disagree as 2 and strongly disagree as 1. Items marked with an asterisk were reverse scored. The number in parentheses for each item is the number of that item in Enochs and Riggs’ (1990) original STEBI-B. Enochs and Rigg’s questionnaire was abridged and then further modified in two ways. In most items ‘science’ was replaced with ‘NOS’, and Question 7 (13 in the original) has been modified according to Bleicher’s (2004) re-examination of factor analysis and reliability of STEBI-B.

An increase in self-efficacy of the cohort is shown by an increase in mean score. It can be seen that for each of the items there was an increase in mean self-efficacy score of the cohort after peer teaching and again after microteaching. This is a positive finding. The only exception is Item 8, concerning student achievement in science being directly related to teacher effectiveness, where there was a slight decrease in the cohort mean after microteaching. By this stage of the course the students had spent more time teaching in schools, so this response could reflect a more realistic understanding of the social, cultural, and political influences on teaching and learning.
Table 7.5 Science teacher efficacy belief survey (n=74)

<table>
<thead>
<tr>
<th>#</th>
<th>Item</th>
<th>Mean</th>
<th>Pre teaching</th>
<th>Post peer teaching</th>
<th>Post microteaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I will continually find better ways to teach NOS. (2)</td>
<td></td>
<td>-</td>
<td>4.36</td>
<td>4.78</td>
</tr>
<tr>
<td>2*</td>
<td>Even if I try very hard, I will not teach science as well as I will most subjects. (3*)</td>
<td>2.19</td>
<td>4.15</td>
<td>4.82</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I know some approaches to teach NOS effectively. (5)</td>
<td>1.08</td>
<td>4.92</td>
<td>4.93</td>
<td></td>
</tr>
<tr>
<td>4*</td>
<td>I will generally teach NOS ineffectively. (8*)</td>
<td>-</td>
<td>3.96</td>
<td>4.17</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The inadequacy of a student’s science background can be overcome by good teaching. (9)</td>
<td>2.15</td>
<td>3.82</td>
<td>3.87</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I understand NOS concepts well enough to be effective in teaching elementary science. (12)</td>
<td>1.25</td>
<td>4.02</td>
<td>4.83</td>
<td></td>
</tr>
<tr>
<td>7*</td>
<td>Increased effort in NOS teaching produces little change in students’ NOS understanding. (13*)</td>
<td>-</td>
<td>4.76</td>
<td>4.93</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Students’ achievement in science, including NOS, is directly related to their teacher’s effectiveness in science teaching. (15)</td>
<td>1.93</td>
<td>3.95</td>
<td>3.42</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>I will typically be able to answer my students’ NOS questions. (18)</td>
<td>1.74</td>
<td>3.91</td>
<td>4.01</td>
<td></td>
</tr>
<tr>
<td>10*</td>
<td>I wonder if I will have the necessary skills to teach NOS. (19*)</td>
<td>1.93</td>
<td>4.17</td>
<td>4.29</td>
<td></td>
</tr>
<tr>
<td>11*</td>
<td>Given a choice, I will not invite the principal to evaluate my science teaching. (20*)</td>
<td>2.07</td>
<td>2.26</td>
<td>4.06</td>
<td></td>
</tr>
<tr>
<td>12*</td>
<td>When a student has difficulty understanding a NOS concept, I will usually be at a loss as to how to help the child understand. (21*)</td>
<td>1.27</td>
<td>3.72</td>
<td>4.16</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>When teaching NOS I will welcome students’ questions. (22)</td>
<td>-</td>
<td>3.87</td>
<td>4.65</td>
<td></td>
</tr>
<tr>
<td>14*</td>
<td>I do not know what to do to turn students on to science. (23*)</td>
<td>2.93</td>
<td>4.25</td>
<td>4.43</td>
<td></td>
</tr>
</tbody>
</table>

Note: Use of * indicates items which are reversed scored.

Surveys of student perceptions of usefulness of teaching and learning approaches

Finally, Table 7.6 shows the comparison of pre- and post-surveys of student perceptions of the teaching and learning approaches most useful in developing NOS understanding. All of these students had spent at least 3 years studying at University before being accepted into the one-year Graduate Diploma of Teaching (Primary Specialisation). The pre-course data reflects their university experience prior to this course. The post-course data asked them to comment specifically on this science education course. Substantial increases in the cohort mean are seen in the items ‘I learn(t) through the workshops’, ‘I learn(t) through teaching others’ and ‘I learn(t) from my peers’. Smaller increases are seen for the items, ‘I learn(t) through the course readings’ and ‘I learn(t) through attending lectures’. A decrease is evident in the item ‘I learn(t) through studying for the test’. It should be noted that the
workshop sessions in this course were laboratory based, and comprised hands-on activity, group work and discussion. Students may not have participated in such workshops in their previous University study.

Table 7.6 Pre- and post-surveys of student perceptions of the teaching and learning approaches most useful in developing NOS understanding

(\(n=74\))

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-course</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>N</td>
<td>A</td>
<td>SA</td>
<td>Mean</td>
<td>D</td>
<td>N</td>
<td>A</td>
</tr>
<tr>
<td>I learn through attending lectures</td>
<td>3</td>
<td>7</td>
<td>47</td>
<td>88</td>
<td>4.51</td>
<td>-</td>
<td>41</td>
<td>104</td>
</tr>
<tr>
<td>I learn through workshops</td>
<td>-</td>
<td>141</td>
<td>3</td>
<td>1</td>
<td>3.03</td>
<td>-</td>
<td>32</td>
<td>113</td>
</tr>
<tr>
<td>I learn through the course readings</td>
<td>18</td>
<td>54</td>
<td>41</td>
<td>32</td>
<td>3.88</td>
<td>5</td>
<td>122</td>
<td>18</td>
</tr>
<tr>
<td>I learn through teaching others</td>
<td>2</td>
<td>94</td>
<td>49</td>
<td>3</td>
<td>3.37</td>
<td>-</td>
<td>27</td>
<td>118</td>
</tr>
<tr>
<td>I learn from my peers</td>
<td>1</td>
<td>92</td>
<td>49</td>
<td>3</td>
<td>3.37</td>
<td>-</td>
<td>48</td>
<td>97</td>
</tr>
<tr>
<td>I learn through studying for the test</td>
<td>-</td>
<td>3</td>
<td>75</td>
<td>67</td>
<td>4.40</td>
<td>-</td>
<td>110</td>
<td>35</td>
</tr>
</tbody>
</table>

Discussion

Preservice teachers’ lesson planning was analysed to identify components of PCK, according to the five dimensions of Magnusson et al.’s (1999) model (Tables 7.1 & 7.2). Concerning knowledge of the curriculum, most of the preservice teachers demonstrated in their peer teaching lesson plans a knowledge of curriculum related to science content by being able to correctly identify science content-related achievement aims and objectives from the curriculum, and from these being able to create appropriate learning outcomes for a specific teaching session. However, far fewer students did so for NOS. Their focus for teaching was science content rather than teaching through NOS. In contrast, in their microteaching lesson planning for children later in the course, all preservice teachers identified NOS-related achievement aims and objectives from the curriculum and the majority (94%) created appropriate NOS-related learning outcomes for their teaching session. Similarly, in their microteaching most (90%) were able to demonstrate, in their use of diagnostic assessments, their understanding of the need for knowledge of students’ understanding of NOS.

In order to demonstrate Magnusson et al.’s knowledge of representations and instructional strategies, the preservice teachers needed to turn their curriculum knowledge and knowledge of students’ understanding of NOS into specific learning experiences (for their peers or their students). In their peer teaching 61% of the preservice teachers did so, compared with 91% in their microteaching planning. The greater percentage of preservice teachers who gave evidence in their microteaching of NOS-specific strategies compared with their peer teaching could indicate an increase in awareness of available NOS resources, or an increase in ability to modify or develop such materials, or both.
Akerson et al.’s (2007) review of elementary science curricula shows that these documents generally do not suggest how to embed NOS within the content. Therefore, teachers need assistance to integrate NOS into their own science teaching (2007). This is particularly so with the New Zealand curriculum. Appleton (2006) has described elementary teachers’ desire for pre-packaged ‘activities that work’ and suggests that, indeed, these may play an important role in the development of elementary teachers’ PCK for teaching science. While avoiding ‘cookbook’ NOS lessons for preservice teachers to implement (Schwartz & Lederman, 2002), this research study supports Appleton’s suggestion that some level of assistance is needed to help preservice teachers develop their pedagogical repertoire and abilities to teach and assess NOS. PCK is developed through practice, through the act of teaching and thinking about it. Thus to develop PCK, a course must include opportunities to teach and to reflect upon that teaching.

The smallest shift was seen in assessment of NOS, which is consistent with findings that teachers may lack sufficient knowledge of strategies for assessing students’ ideas about NOS (Hanuscin et al., 2011). These findings align with research by Magnusson et al. (1999) that suggests the development of teachers’ PCK may be uneven, in that changes in knowledge of one component (e.g., knowledge of instructional strategies) may not be accompanied by changes in other components (e.g., knowledge of assessment). Knowing what to assess, as well as how to assess, is an important part of NOS PCK – and of a teacher’s capability to continually develop their teaching of NOS.

In terms of orientation for teaching, a shift was seen in lesson planning for microteaching towards teaching NOS within a context related to the students’ real life worlds or to socioscientific issues. This shift is well illustrated by comments in the preservice teachers’ microteaching evaluations. For example:

> Teaching children science with NOS as the overarching strand compels me to teach science in a way very different from the science I remember at school. NOS pushes me towards a science teaching that is relevant and real life for the children – even provocative and challenging if it is cloaked in a current contentious issue like climate change. (MT, SE, S71)

Many of the preservice teachers showed a shift in their self-evaluation from comments indicating a technical or practical understanding and teaching of NOS, to comments reflecting a well-contextualised, relevant, socioscientific embedded teaching and learning of NOS. This suggests more informed, internalised and coherent views of NOS. It is consistent with Abd-El-Khalick’s (2005) findings with a cohort of preservice secondary science teachers enrolled in a philosophy of science course, where in the latter part of the course the observed shift in thinking allowed them to use “their NOS understanding as a lens to reflect on their science learning experiences and contemplate ways in

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16 To code student responses, the following abbreviations were used: MT – microteaching; PT – peer teaching; SE – self-evaluation; S – student.
which these understandings would allow them to escape the traditional molds in which science teaching and learning are often cast” (p. 33).

Analysis of the self-evaluations of the peer teaching and microteaching (Tables 7.4 & 7.5) show each of Bandura’s four dimensions of self-efficacy and show an increase in the representations of each of these dimensions when comparing microteaching self-evaluations with peer teaching self-evaluations across the cohort. In the microteaching self-evaluations, mastery experiences were evident in comments from almost all of the preservice teachers, consistent with Bandura’s (1997) suggestion that mastery experiences are the most powerful in developing self-efficacy.

Preservice teachers’ self-evaluations of their peer teaching also showed substantial evidence of Bandura’s vicarious experiences when they made references to seeing their peers successfully teaching NOS. Vicarious experiences are those in which a person sees a behaviour modelled by another person, so they feel they could do it too. Palmer (2006) notes that vicarious experiences are particularly relevant when people have little previous experience of the task in hand – as with teaching NOS – where seeing others perform competently encourages the belief that they could do likewise. Similarly, Zimmerman and Kitsantas (2002) found that a ‘coping model’, of a person who gradually improved his or her technique, was more effective in raising self-efficacy among observers than a ‘mastery model’, of a person who performed that technique flawlessly.

Bandura’s third dimension of efficacy information, verbal persuasion, was evident in the preservice teachers’ reporting of the positive feedback they received from their peers, such as:

I got a real buzz from the positive feedback I received from my peers. It is really encouraging for your teaching efforts to be so well received – particularly when all this NOS is so new to me. (PT, SE, S62)

Bandura (1997) posited that “People who are persuaded verbally that they possess the capabilities to master given tasks are likely to mobilise greater effort and sustain it than if they harbor self-doubts and dwell on personal deficiencies when difficulties arise” (p. 101).

It was also evident in their reporting of feedback from the children they taught in microteaching. For example:

I was so encouraged by how engaged the students were in the lesson, and by all the comments they made about how much they enjoyed it. Very empowering for someone like me who before this course was not looking forward to teaching science at all – let alone NOS that I had never heard of! (MT, SE, S18)

Regarding the fourth source of self-efficacy, through physiological and affective states, Bandura posits that higher self-efficacy is achieved when people treat anxiety and fear as normal responses that even highly competent individuals may experience in certain situations. It is apparent in their self-
evaluation comments that many of the preservice teachers used their feelings of stress, anxiety, or nervousness in a positive way in their peer teaching or microteaching, rather than allowing such feelings to debilitate or overwhelm. For example:

My nervousness to teach my peers was exceeded only by my determination to be well prepared. It went surprisingly well! (PT, SE, S37)

Although direct comparison of preservice teachers’ self-efficacy in peer teaching with self-efficacy in microteaching is complicated by a multiplicity of variables, self-efficacy over the duration of the course as evidenced by the repeated STEBI-B (1990, modified 2004) (Table 7.5) does suggest an increase in reported self-efficacy from pre-course to post-peer teaching, and again to post microteaching. As it is argued that teachers’ behaviour in classrooms is highly influenced by a belief that their teaching strategies would be effective (response-outcome expectancies) and by their perceptions of their ability to teach (efficacy expectations), it is proposed here that peer teaching and microteaching provided opportunities for preservice teachers to develop self-efficacy to teach NOS. This is consistent with other studies showing that science methods courses can positively influence students’ confidence to teach science (Appleton, 1995; Cantrell, Young, & Moore, 2003; Palmer, 2001). Similarly, Akerson and Volrich (2006) found that a student teacher who had sufficient understanding of NOS, as well as intentions and motivation to teach NOS, effectively implemented strategies for explicitly emphasising NOS within her instruction.

The usefulness of microteaching and peer teaching is further supported by the preservice teachers’ reported views on how they best learn (Table 7.6). The items “I learn from my peers” and “I learn from teaching others” were the two items that showed the greatest increase in cohort mean from pre-course to post-course. For both items, 100% of the preservice teachers agreed or strongly agreed with the statements. This self-reported data lends support to the assertion that microteaching and peer teaching are effective approaches to develop NOS PCK and self-efficacy.

**Concluding Thoughts**

The purpose of this research study was to add to the body of knowledge concerning the effective translation of NOS understandings into practice. Peer teaching and microteaching have been examined as teaching approaches to develop preservice teachers’ PCK for NOS and self-efficacy to teach NOS.

Lesson planning, self-evaluations of peer teaching, and microteaching show evidence of PCK for NOS along each of Magnussons’ five dimensions of PCK. Self-evaluations of peer teaching and microteaching show each of the four components of Bandura’s (1997) model for self-efficacy. The findings of the Science Teacher Efficacy Belief Instrument (STEBI-B) and the pre- and post-surveys of student perceptions of the teaching and learning approaches most useful in developing NOS understanding support the premise that peer teaching and microteaching allow for the development of
self-efficacy. These are useful findings, since limited content and pedagogical content knowledge, and low efficacy have been linked to teachers avoiding science in the classroom, or teaching only within their comfort zone where they feel they can control the classroom (Appleton, 2006).

In contrast, Bandura’s (1997) review of studies of teacher behaviour found that teachers who have a high sense of self-efficacy have a strong commitment to teaching, tend to regard learning problems as surmountable, make extensive efforts to motivate students, devote more class time to academic work, provide students with guidance and praise for their accomplishments, and in general are associated with higher levels of student achievement. Given that each of these behaviours will also enhance the teaching of NOS, it is suggested that a preservice teacher education with an emphasis on microteaching and peer teaching can help develop preservice teachers’ NOS PCK and self-efficacy in a way that assists translation of informed NOS views into classroom teaching.
Chapter 8:  
Conclusion

Transformation. That is the chief purpose of education – that all who are involved should transform their capacities to act, think, and feel in ways that contribute to the common good and enrich their own lives. (Wells, 2001, p. 1)

The impetus for the establishment of this research programme was the release of the revised New Zealand curriculum in 2007, mandating required learning for all students from Years 1–13 from 2010. Consistent with science curricula internationally, the New Zealand revised science curriculum now has a much stronger and more explicit focus on the nature of science, describing it as “the overarching, unifying strand” and necessary in order that students may “use scientific knowledge and skills to make informed decisions about the communication, application, and implications of science as these relate to their own lives and cultures and to the sustainability of the environment” (Ministry of Education, 2007a, p.28). This imperative of NOS as a curriculum requirement serves as a very strong driver for prioritising NOS in teacher education courses, and as an external motivator for teachers to prioritise NOS in their science teaching.

As a preface to this research programme, 6 months was spent working with teachers in a large primary school. The purpose of this school-based work was to identify the understandings of NOS in a cohort of practising teachers and to identify any possible barriers to NOS implementation that could be effectively addressed in a preservice primary teacher education programme. Consistent with the research literature (e.g., Iqbal, Azam, & Rana, 2009; Lederman, 2007), the teachers’ understanding of NOS was found to be inconsistent with contemporary views of NOS. This is not to assume a deficit model of teacher knowledge, but rather to acknowledge the shift in curricular priorities, the need for attention to be paid to scientific literacy among the citizenry in general and, with regard to this research, the scientific literacy of teachers and preservice teachers in particular.

The challenge for teacher education providers is to ensure that their programmes adequately prepare teachers to teach this unfamiliar and core strand of science. Developing science education courses that support thinking and teaching about NOS is problematic given the short time frame of teacher education programmes in general, and the even shorter time frame of the science education component of such programmes. Research indicates that teachers find it difficult to teach curricula that emphasise NOS (e.g., Abd-El-Khalick, 2013). Thus a key driver for this research programme has been to identify ways that teachers might be better prepared to face such challenges.

The aim of this research was to explore aspects within a science education course that positively
influence preservice and inservice teachers’ views of NOS and better equip them to translate these views into their classroom teaching. Five phases of this research were conducted with five separate cohorts of students. The first phase involved inservice teachers enrolled in the University to upgrade their existing qualifications; the subsequent four phases were with preservice teachers. The primary motivation for the ongoing research has been a desire to improve the teaching of NOS by beginning teachers. The intention has been to use the outcomes of research in each phase to inform changes in practice within the course for successive cohorts. This iterative approach has also been designed in a way that directly involves the students in research of their learning, including the meta-level of why the research was being conducted, awareness of their vital role within this research programme, and as a provision of an exemplar and stimulus for them to develop a research orientation towards their own practice.

Consistent with previous research (e.g., Akerson et al., 2006; Gess-Newsome, 2002), the participants expressed limited views of the majority of the target NOS aspects at the commencement of the study – in each of the five phases of the research. During each phase, participants engaged in a variety of course components specifically designed to facilitate the development of their views of NOS. This study has critically analysed the effectiveness of various course components designed to facilitate the development of participants’ views of NOS, and identified and investigated the various factors that mediated the development of these NOS understandings.

The initial broad research questions which directed the overall study were:

- What is the initial NOS understanding of a cohort of practising teachers?
- What is the initial NOS understanding of a cohort of preservice teachers?
- What strategies can be used to challenge existing misconceptions and/or develop robust NOS understandings?
- What strategies can be used to develop and refine pedagogical content knowledge for NOS in preservice teacher education?

The context of each phase of the research was a science methods course of one-semester duration (approximately 10–15 weeks). A constructivist research perspective guided the study, and the research strategy employed was case study research. The study applied trustworthiness criteria (Guba & Lincoln, 1989) and methodological triangulation protocols (Creswell, Plano Clark, Gutmann, & Hanson, 2003), and also considered the perspective and role of the researcher, to ensure the study’s findings and interpretations were valid. There are, of course, many ethical issues associated with conducting a research project so closely linked to the student teachers’ own course, particularly with the researcher being a lecturer in the courses. Therefore the research and lecturing practice has
adhered very strictly to the ethical guidelines of the University of Auckland Human Participants Ethics Committee (UAHPEC).

Chapter 2 of the thesis provided an overview of research literature in the field of NOS and in doing so established a rationale for researching NOS in this study. It briefly examined the last 150 years of advocacy for the inclusion of NOS in science education and shows that ensuring students have an understanding of NOS has been one of the most consistent and central elements of science education reform over the last 20 years, as reflected in reform documents and curricula, (e.g., Abd-El-Khalick et al., 2008; Duschl, 1990; Hodson, 2008, 2009a; Millar & Osborne, 1998; Southerland et al., 2007) and that NOS as a requirement of scientific literacy is now clearly established as an important learning objective of science curricula in many countries. The importance given to NOS in official curriculum documents has become so evident that Dagher and BouJaoude (2005) have stated: “improving students’ and teachers’ understanding of NOS has shifted from a desirable goal to being a central one for achieving scientific literacy” (p. 378), while Lederman (2007) commented that, “when it comes to NOS, one is hard pressed to find rhetoric arguing against its importance as a prized educational outcome” (p.831).

Having established the importance attached to NOS globally, Chapter 2 explored the breadth of definitions afforded to the complex notion. It was argued that since representations of science change in response to changing priorities, problems and situations, then it follows that our understandings of NOS will also change. The review presented in Chapter 2 showed that this is evident historically when considering the works of philosophers such as Popper (1959), Kuhn (1970) and Lakatos (1970) and is equally apparent in current debate around tenets of NOS proposed over two decades ago by Lederman (1992). With most science educators acknowledging that issues regarding NOS are still not settled, a brief discussion of the views of NOS posited by Lederman (1992), McComas and Olson (1998), Rudolph (2000), Clough (2007), Hodson (2009a) and Mathews (2012), among others, was provided. Wong and Hodson (2009) shed further light on this discussion in reporting their examination of the practices of scientists, which clearly demonstrates that there is no single set of NOS elements to fit all disciplines, contexts and time periods. In consequence, decisions were required concerning which views of NOS to present to students and report on in this research programme.

Throughout the research, tenets of NOS were used, although as a starting place for understanding rather than specific learning outcomes. Following the lead of Clough (2007), NOS tenets were always discussed as questions and presented within a much broader view of NOS, rather than as ‘something to be learnt’. The view remained uppermost throughout the research that rather than promoting the critical thinking which lies at the core of the rationale for including NOS, such a list of tenets can short-circuit critical thinking altogether. A much broader view of NOS was increasingly adopted over the duration of the research, following Wittgenstein’s (1953) terminology of ‘family resemblance’ and
Matthews’ (2012) ‘features of NOS’. Tenets were used as doors to a broadening of understanding of NOS as students move through their science education. Matthews makes essentially the same point when he states that students have “to crawl before they can walk, and walk before they can run” (p.21).

Chapter 2 also established that the rationale for teaching NOS takes various forms. Since scholars have long described NOS understanding as an integral component of the broader construct of scientific literacy, with an understanding that NOS is at the heart of virtually all definitions of scientific literacy (e.g., Laugksch, 2000; McComas et al., 1998; Shamos, 1995; Schwab, 1962), it follows that arguments for the teaching for scientific literacy become arguments for the teaching of NOS. Therefore in the research programme of this thesis, attention was paid to Taber’s (2010) proposal that this is an urgent imperative for various reasons, including: increasing the number of talented young people choosing to enter science (and therefore contributing to economic development); countering a perceived conflict between science and non-science/anti-science; and ensuring responsible public decision-making in areas of major economic, technological and environmental importance. Hodson’s (2006) grouping of Thomas and Durant’s (1987) arguments into the three categories of perceived benefits to science, benefits to individuals and benefits to society as a whole, were also presented in the course. Underpinning this research was the belief that teachers’ and student teachers’ motivation to teach NOS effectively would be enhanced by their recognising these compelling arguments to teach NOS and reasons why NOS understanding is important.

Both teachers and student teachers need to recognise that there are these compelling reasons for teaching NOS in order to be motivated to teach NOS. In other words motivating teachers and student teachers to teach NOS effectively is enhanced by presenting these arguments as to why NOS is important. To pick up the gauntlet to teach NOS in such a way that equips and motivates their students to participate with science in their own lives, and moves them towards functional and critical scientific literacy, requires both sound understanding of NOS and a strong commitment to teach for change. Again, this presents a challenge for preservice teacher education programmes and was a further rationale for this study.

Chapter 2 then reviewed the literature on historical and current views of NOS, citing an extended body of research indicating that the views of NOS held by students and also by teachers are not consistent with contemporary conceptions of the scientific endeavour. This is as true in New Zealand as it is internationally. For teacher education this raises an issue that required further research, particularly given that science teaching cannot escape conveying an image of NOS to students that reflects the teacher’s own understanding. Indeed, the views teachers hold will become the ‘hidden curriculum’ and will manifest in the messages teachers implicitly convey about science to their students in their talk about the subject, the content they select to teach, the type of activities they plan and the
experiences they provide (Hodson, 2008). Chapter 2 noted that the NOS misconceptions held by science teachers, their students and the general public, presented in popular media, promoted in textbooks and resource materials, and taught in classrooms, coalesce to form a powerful self-supporting network that continues the cycle of misconceptions, misunderstandings, distrust and disinterest generation after generation. It is this cycle that needs to be addressed in teacher education programmes.

Given the widespread consensus that effective teachers constitute the critical factor for student learning (Akerson et al., 2010) and that teachers’ beliefs and knowledge may be regarded as a crucial leverage point to effect a change in the classroom, Chapter 2 then examined literature related to teachers as change agents. The issues surrounding the complexities of translation of NOS understanding into classroom teaching were raised in Chapter 2, and became the rationale for the research on microteaching, peer teaching and planning as reported in Chapter 7. The concept of Pedagogical Content Knowledge (PCK), as represented in the research literature, was discussed in light of the body of literature suggesting that to effect translation into practice, what is needed is PCK of NOS in addition to content knowledge of NOS. The paucity of research on PCK needed for specifically teaching NOS provided further rationale for the research throughout the programme and, in particular, for the final phase of the research as reported in Chapter 7. Further understanding of the ways teachers develop NOS subject matter knowledge for science, that is, epistemic knowledge of science, and develop effective methods for teaching it (NOS PCK) are needed if implementation of curricula with a focus on scientific literacy is to be successful. The research reported in the thesis adds substantially to this needed literature.

Chapter 2 then moved to a discussion of NOS-specific pedagogical approaches for teaching NOS, which fall broadly into two groups: implicit and explicit. There is general agreement that explicit NOS instruction is more effective than implicit approaches (Akerson et al., 2007; Bell et al., 2011; Lederman, 2007; Rudge and Howe, 2009; Schwartz et al., 2004). This prompts questions about the format this explicit instruction should take, including the distinction between explicit teaching of NOS as non-integrated or as integrated with the process skills and/or science content being taught. Chapter 2 reported that there is, as yet, no clear consensus on whether NOS is best taught integrated or non-integrated, contextualised or decontextualised. This was the rationale for the research reported in Chapter 3 – to provide further research data to inform this issue. On the one hand, it has been suggested that to separate NOS from content reduces cognitive load and therefore facilitates the development of NOS understanding. On the other, separating NOS as non-integrated instruction adds yet another component to an already overcrowded curriculum, and must, in a sense, mean replacing science content material with units or modules of NOS. It is also suggested that isolating NOS issues may make it more problematic for students to make links between the same NOS ideas when they
appear in different contexts (Taber, 2010). Some have cautioned that non-integrated instruction with its lack of authentic context, is unlikely to engender the robust understandings of NOS that would serve as a foundation for addressing NOS in the teachers’ own science instruction (Brickhouse et al., 2000; Clough & Olson, 2001; Smith & Scharmann, 2008).

Bell et al. (2011) note that research on situated learning (e.g., Brown, Collins, & Duguid, 1989) supports a cautionary stance on students’ ability to view NOS as an integral component of science when it is taught apart from what they perceive as ‘real’ science content. The argument was presented in Chapter 2 that the integration of NOS into content in a real world application or applying NOS within socioscientific issues is a deeper level of integration or contextualisation and is justified from a situated learning perspective (Brown et al., 1989; Lave & Wenger, 1991). In other words, NOS learning is enhanced when learned in authentic contexts. In their review of research reports looking at the effectiveness of SSI as contexts for science education, Sadler and Dawson (2012) found compelling evidence that the inclusion of SSI in science curricula supports the development of science content knowledge, NOS understanding, interest and motivation and argumentation. Schwartz and Lederman (2008) and Wong and Hodson (2009) recommend the use of scientists’ case studies for providing rich examples of NOS from contemporary experiences in the scientific community. Picking up this argument, the use of an authentic context was specifically researched in the third phase of this research and is reported in Chapter 4.

The review of research studies reported in Chapter 2 argued that regardless of whether instruction is contextualised or decontextualised, the most effective approaches to teaching NOS are those that have a substantial reflective component. Literature reviewed by Schwartz (2004) suggests that in order to construct robust understanding of NOS, students need opportunities to engage in reflective activities and reflective discussions, to reflect upon and explain their ideas about NOS, to discuss the strengths and limitations of those ideas, to assess the consistency of their ideas with those of others and to reflect on their own views and on the NOS aspects that occur within the context of a science-based activity or science content being learnt. Indeed, Schwartz (2004) has proposed that reflection on NOS, perhaps in conjunction with, and in direct reference to, inquiry activities in which the students are engaged may be the “critical pedagogical component” (p. 8) required for the successful teaching of NOS. Therefore, in each of the five phases of this research programme, providing opportunities for reflection was considered essential.

Research studies have evaluated reflection structured in a variety of ways, including reflective discussion (Schwartz & Lederman, 2002), reflective journaling or journals-based assignments (Bell et al., 2003; Schwartz, 2004), interviewing practising scientists about their work (Morrison et al., 2009), using metacognitive strategies such as concept mapping, researching the development of peers’ NOS understanding (Abd-El-Khalick & Akerson, 2009), and using authentic contexts and SSIs. Structuring
a course to provide multiple opportunities for this level of reflection is problematic given the time constraints of most teacher education programmes. This was certainly found to be the case in the first and second phases of this study. Further research was required to address this issue. This prompted the research reported in Chapters 5 and 6, in which Web 2.0 technology was used to provide increased opportunities for reflection. If reflection on NOS is a key, then within our programmes maximum opportunities for reflection should be intentionally structured. Sensitivity to the short time frame also compels us to consider the potential for learning with new technologies, such as Web 2.0 to facilitate the reflection required for NOS understanding. Here the focus was not the tool itself, but how the tool could be employed in a specific context to enhance effective pedagogy, as reported in Chapters 5 & 6.

In summary, the purpose of the review in Chapter 2 was to situate the current study within the broader context of NOS research, and to consider recent NOS teaching approaches designed to develop or improve students’ and teachers’ views of NOS. This conclusion highlights the key findings, arguments and contributions of the present study and discusses the implications of these findings for teacher education programmes. The study’s limitations are acknowledged and suggestions for future research offered.

**Key Findings**

**The first phase**

The first phase of this research, as reported in Chapter 3, involved a cohort of practising teachers ($n=25$) enrolled in a university science education course to upgrade their teaching qualifications. At the time, the New Zealand curriculum had been recently revised and within this revision NOS was given much more emphasis. Informed by the literature review reported in Chapter 2, teaching in this course was explicit for NOS, provided repeated opportunities for reflection, and used generic science content-free activities (which illustrated aspects of NOS, but contained no science content). It acknowledged findings from many studies over the past three decades showing that students come into science instruction already holding deeply rooted conceptions and ideas about the phenomena and concepts to be taught – conceptions that are not always consistent with the science views or that are even in stark contrast to them. The reflective approach used in this first phase of the research provided structured and guided opportunities for learners to examine their own views and, in this case, identify the discrepancies between their NOS conceptions and those presented.

Findings from this research have contributed to the literature concerning whether NOS is best taught integrated or non-integrated, contextualised or decontextualised. To date, most NOS research studies have adopted *either* an integrated *or* non-integrated approach (Lederman, 2007). The point of difference in this study was that it was structured so that the teachers could approach the generic activities either as integrated or non-integrated with the science content. In other words, the design of
this research provided the opportunity for both. Each of the generic science content-free activities was strategically located within a topic to which it could be related. This allowed teachers who had sufficient conceptual understanding of the NOS tenets in the activity, and of the science content, to contextualise the NOS tenets within the science content, for deeper conceptual change. So the generic NOS activities could be approached by the teachers as non-integrated pull-out activities (Lederman, 2007) or as a NOS activity closely related to the context (integrated).

This structure provided a cognitive space within which the teachers could learn in either a non-integrated and/or an integrated way (Clough, 2006). Since the course was structured to encourage teachers to make journal entries at any time during the sessions, as well as during a set time at the end to provide multiple opportunities for reflection, key findings could be drawn from the analysis of the teachers’ entries in these reflective journals.

It was anticipated that the reflective journal writing would allow teachers the opportunity to reflect on the NOS tenets in the generic NOS activity or the science content area they were reflecting on and writing about. It was also envisaged that some would be able to make the links between the generic NOS activity being carried out and the content area in which it was embedded. As anticipated, the journal entries did show that the NOS activities facilitated the establishment of connections between the tenets in the generic NOS activities and the tenets in the science content, and vice versa. However, even more significantly, the role of the generic NOS activities in scaffolding a deeper level of reflection can be seen in the reflective comments recorded by the teachers where, as the course progressed, teachers would frequently relate the NOS tenet being explicitly taught in a content area to a previous generic NOS activity. This suggests that the generic NOS activities play a mediating or linking role between seeing NOS tenets in the generic NOS activities and seeing NOS tenets within science content.

Data from the teachers’ journals showed that these generic activities also appeared to have scaffolded their thinking to recognise the inter-relatedness of the tenets, rather than seeing them as discrete entities – which could be a key indicator of the depth of understanding of the teachers’ NOS understanding. With regard to the debate about whether NOS is better taught embedded within the science content or as a separate pull-out topic (Lederman, 2007), the research has provided data to argue that a course of learning should include both in order to cater for the level of conceptual understanding of all participants. It strongly supports Clough’s (2006) notion of a continuum ranging from decontextualised to moderately and highly contextualised, with extensive scaffolds back and forth along this continuum. The research reported in Chapter 3 showed that teachers were provided with, and used, opportunities to move themselves backwards and forwards along a continuum of learning NOS as decontextualised or contextualised, and presents evidence to support the use of generic activities to scaffold the learners’ use of tenets as doors to a deeper understanding.
The key findings from the first phase of this research concern the positive shifts in understanding that were seen using a course with repeated opportunities for reflective writing, generic science content-free NOS activities, and a course structure that allowed for both integrated and non-integrated approaches. The use of generic activities provides analogies for initial understanding and also facilitates the movement along a continuum of decontextualised to contextualised NOS teaching and learning.

The second phase

The second phase of this research was informed by the body of literature suggesting that, from a situated learning perspective (Brown et al., 1989; Lave & Wenger, 1991), NOS learning is further enhanced by presentation in authentic contexts. Authentic contexts can be those which link science to the students’ real world, or engage students with SSIs, or present them with scientists’ case studies providing rich examples of NOS from contemporary experiences in the scientific community (Schwartz & Lederman, 2008; Wong & Hodson, 2009). SSIs can provide a powerful context in which teachers can integrate instruction about science content and NOS in ways that help “students envision the connection that exists between more global issues and themselves” (Sadler, 2004, p. 531). They also have the potential to empower students and better prepare them to be informed decision-makers as adults (Driver et al., 2000). It has been argued that integrating current SSIs, the history of science, and contemporary science stories can powerfully contextualise NOS for deeper understanding (e.g., Clough, 2006; Hodson, 2003, 2009a, 2011; Khishfe & Lederman, 2006; McComas, 2008; Walker & Zeidler, 2007). The literature suggests that teaching NOS in this highly contextualised manner is important in persuading teachers that NOS instruction need not detract from, and can likely promote, science content learning (Clough & Olson, 2008). If the goal is scientific literacy, then this capacity to appreciate NOS ideas in current SSIs and in the historical development of scientific ideas is critical. The goal becomes one of functional NOS for scientific literacy rather than knowledge of NOS tenets alone – the difference between reducing understanding to solely a cognitive outcome, and seeking a deeper and broader hermeneutic understanding in which NOS ideas will be nuanced differently in different domains of science.

To this end, the next phase of the research, reported in Chapter 4, investigated the potential of using an authentic context to understand the characteristics of NOS, and also of the nature of technology (NOT). The cohort in this phase of the research were preservice primary teachers (n=46) in their third year of a Bachelor of Education programme. The course was an optional course on both scientific and technological literacy, so understanding of NOT was researched alongside understanding of NOS. Based on findings from the first phase of the research, an explicit approach to NOS (and NOT) teaching was still used with both decontextualised and contextualised teaching of NOS (and NOT), accompanied by guided practical activities emphasising the essential nature of these domains.
(Akerson & Donnelly, 2010). In addition, the course content was set within the authentic context of the issues of UV radiation. This context is personally relevant to New Zealanders as the incidence of melanoma is around four times higher than in Canada, the US and the UK. Indeed, two in three New Zealanders will develop a non-melanoma skin cancer during their lifetime and one in 17 will develop a melanoma cancer.

The goal of the research, therefore, was to investigate the potential of providing an authentic resource, accompanied by explicit teaching of NOS (and NOT), to develop preservice teachers’ understandings of NOS and NOT. This authentic context was accessed via a web-based resource, ‘You, Me and UV’ (www.sciencelearn.org.nz), which provided preservice teachers with virtual access to the science research community.

There have been few research studies upon which to draw when considering the question of context in NOS instruction. Bell et al.’s (2011) review of such studies suggests that while setting instruction in the context of authentic science content and issues may be desirable, it may not be necessary when the primary goal is for students to understand key aspects of NOS. This was certainly evident in the first two phases of the research, where the teachers’ views of NOS developed into a more robust understanding over the duration of the course – without focused attention to an authentic context. However, the context in which NOS instruction is situated may be more important when the goal is to encourage teachers to incorporate NOS into their own instructional practice, and is certainly important if the goal is functional NOS for scientific literacy. This premise provided the rationale for this second phase of the research.

The research described in Chapter 4 was informed by situated learning theory, which argues that understandings are best constructed within learning situations that are authentic (Jones & Baker, 2005; Rodrigues, 2006; Schwartz et al., 2004). In science and technology, such authentic contexts can be characterised as ‘Post-Normal’ (Funtowicz and Ravetz (1993), that is, where “facts are uncertain, values in dispute, stakes high and decisions urgent” (Funtowicz & Ravetz, 2003, p.1) and where not all the factors needed to inform a decision are necessarily knowable at the time.

Authentic situations elicit opinions from learners and, when the situations are personally relevant or important to them, learners may be motivated to reach a justifiable position on the issue, and choose to take appropriate action (Hodson, 2008, 2011). The authenticity of the context of UV in New Zealand was evaluated against Gilbert’s (2006) four criteria for context-based learning: setting of focal events, behavioural environments, specific language and extra-situational background knowledge. It is argued that in order for the learner to be able to transfer their conceptual understanding to another context, these criteria need to be afforded close attention (Gilbert, Bulte, & Pilo, 2011). This was considered critical since the ability to transfer NOS ideas from one context to another is essential if these
preservice teachers are to be able to teach NOS confidently and effectively. So the potential of this virtual resource to meet these criteria and develop robust views of NOS was closely examined in this research.

A data collection instrument through which preservice teachers were required not only to identify examples of NOS and NOT, but also to justify and illustrate them from the UV context, was able to capture their level of understanding. This addressed the concern that development of an understanding of NOS must move beyond the mere identification of basic NOS characteristics, which can sometimes be reduced to rote repetition of slogans (Clough & Olson, 2008). It was found that the richness of this authentic virtual context allowed these preservice teachers to identify a wide range of illustrative examples from the science of water treatment, melanoma research and radiation measurement to the technological outcomes of sunbeds, sunscreen and waste-water polishing methods. This ability to identify ‘NOS in action’ shows a deeper level of understanding than just being able to state the characteristic. Furthermore, the majority of these preservice teachers was able to provide an adequate or strong justification of their illustrative example. It is proposed that being able to justify an illustration requires an even deeper level of understanding.

This phase of the research showed the potential of an authentic context and the possibilities of a virtual resource to provide access to communities of practice of science and technology research and deepen conceptual and transferable NOS understandings. The key finding was that it is possible for preservice primary teachers to recognise the philosophical underpinnings of these knowledge-developing domains if they are exposed to overt teaching of these characteristics within a rich focal event. However, the study suggested that it was not just exposure to these examples in this focal event that deepened their learning. Rather, it is contended that the data collection strategy that required students to identify NOS and NOT with illustrative examples and specific justifications enabled them to reflect on their developing understandings. This reflective activity provided the framework required to facilitate conceptual change (Morrison et al., 2009; Schwartz & Lederman, 2002). Consequently a key finding here is that authentic contexts coupled with an appropriate reflective framework and overt teaching of NOS have the potential to develop understandings in such a way that learners are able to transfer this understanding from one context to another.

The two phases of the research to this point have explored the use of reflection, decontextualised and contextualised NOS instruction and the use of authentic contexts. What became apparent in these phases was the short time frame of the courses in the light of the extensive conceptual change required. To address this major constraint, the use of Web 2.0 technologies, in phases three and four of the research was investigated and reported on in Chapters 5 and 6. Since it is not usually possible to increase the number of instructional hours of teacher education programmes, nor to extend significantly the number of hours invested by students outside of class time, it provokes us to consider
how to maximise contact time and deepen the reflection required for conceptual change.

The third phase

The third phase of this research involved students enrolled in the Graduate Diploma of Teaching (Primary) programme \((n=42)\). The new teaching approach researched with this cohort focused on augmenting and deepening reflection using Web 2.0 technology. The Web 2.0 platform trialled was Google Wave – loaded onto a class set of laptops for the students’ use and used in all course lectures. Throughout each session, the students were asked to identify specific aspects of NOS which were taught explicitly by the lecturer or covered implicitly in the course content. When students observed such NOS teaching, they entered a brief comment on their laptops; other students and the lecturer were then able to read the comments during the session and add their own responses, if considered appropriate. The students could make contributions or responses to others’ contributions instantaneously in real-time and comments/posts could be seen immediately and easily. Students could also access the site asynchronously in their own time after the sessions and could enter comments or upload web images and video clips (e.g., from YouTube) alongside relevant comments that they or another student had already entered on the Wave.

Data from this phase showed that the Web 2.0 application met the sociocognitive considerations of collaboration, learning how to learn and the ‘idea improvement’ considered essential for knowledge building (van Aalst, 2009). The students had access to the ideas of other students and the data indicated that they attempted to consolidate these in order to improve their own understanding and build richer, deeper knowledge regarding a new collective and individual understanding of NOS within the community of which they are a part (van Aalst, 2006). Rather than simply sharing ideas, the students were able to treat ideas as objects of inquiry open to debate, critical scrutiny, investigation and discussion rather than items of expert knowledge to be blindly accepted. This criticality is essential if the students are to move beyond a superficial knowledge of a handful of simple tenets to a deeper understanding where they are able to apply, analyse and evaluate NOS (Allchin, 2011). Again, these data indicate that the students used tenets as doors and moved from tenets to a deeper, more robust and nuanced understanding of NOS ideas.

For the students as learners, this Web 2.0 application also provided a structure to facilitate repeated and persistent opportunities for reflection, structured and guided opportunities for learners to examine their own views, and identification of the discrepancies between their NOS conceptions and those presented. It addressed Schwartz’s (2004) assertion that reflection on NOS is the critical pedagogical component for the successful teaching of NOS. Since all postings remained as a permanent record, it was readily apparent that there was increasing participation as well as increasing understanding of NOS concepts over the duration of the course. This relates to Lave and Wenger’s (1991) perspective
of situated learning, where understanding is a result of ongoing construction and learning is a process of increasing participation in a community of practice (Lave & Wenger, 1991; Orgill, 2007). Analysis of the time and dates of the students’ postings shows that this increasing participation was evident both in class and in their own time. The capacity to continue learning beyond class time fostered the construction of this knowledge-building community and the transfer of epistemic agency to the students. They were able to assume more responsibility for the advancement of their knowledge and inquiry (Damsa, Kirschner, Andriessen, Erkens, & Sins, 2010; Scardamalia, 2002). The after-session postings were extended to conversations among students about the identification and utilisation of NOS ideas in authentic environments – of NOS in action. It is the potential for mobile learning to bridge pedagogically designed learning contexts, facilitate learner-generated individual and collaborative contexts, while providing personalisation and ubiquitous social connectedness, that distinguishes this approach apart from more traditional learning environments (Cochrane, 2011).

A key finding was that in terms of learning how to learn, this Web 2.0 technology went beyond being merely a discussion platform, to building a communal resource for learning (Scardamalia, 2002) of NOS ideas. A second key finding from the research was that Google Wave also provided a vehicle for feedback from the lecturer to the students and vice versa, and from the students to each other. This aligns with a major conclusion of Hattie’s (2009) synthesis of findings from over 500,000 studies that timely high-quality feedback given against explicit criteria has the greatest effect size on student achievement. Google Wave provided this feedback. Students’ postings provided the lecturer with direct and immediate information about student thinking, thereby challenging the criticism that “the teacher is largely cut off from information about what individual students are learning” (Nuthall, 2007, pp. 919–920). This enabled the lecturer to respond immediately, when appropriate. Google Wave provided an ongoing window for the lecturer into the conceptions and misconceptions of NOS the students were holding. The students’ evaluation of Google Wave indicates that this was a valuable tool in deepening their understanding. Data from the students’ postings on GoogleWave and from their course evaluations clearly demonstrated the potential of a Web 2.0 platform for reflection, to enable them to ‘converse with themselves’, and to create a powerful means of exploring beliefs, attitudes, and learning.

**The fourth phase**

The fourth phase of this research further extended the examination of Web 2.0 technology to facilitate reflection on NOS, this time using ShareFlow as the Web 2.0 platform rather than GoogleWave. The research participants were students enrolled in the three-year Bachelor of Education (Primary Specialisation) degree programme ($n=39$). The one-semester course (in their second year of study) was structured in the same way as for the previous cohort with Google Wave; essentially an explicit–reflective, decontextualised–richly contextualised instructional approach undertaken from within a
metacognitive and learning-as-conceptual change framework. The two key differences were that the students were encouraged more strongly to respond and give feedback to the posts of other students (in addition to posting their own comments) and a new data collection tool, the Cognitive Communication Questionnaire (Andrade et al., 2012), was introduced to enable the researcher to evaluate four dimensions of ShareFlow, namely engagement, learning, student interaction and the functionality of the technology.

Again, as with GoogleWave, the use of ShareFlow was intended to provide an approach that enabled extended engagement with NOS ideas to allow ample time for the reflection needed to effect conceptual change concerning NOS. Teaching for conceptual change required that the target topic (NOS) be made an explicit part of classroom discourse; that learners had structured opportunities to share, discuss and assess the consistency of their ideas; that discourse was metacognitive; that the status of ideas was negotiated; and that justification of ideas was an explicit component of the course (Hewson et al., 1998). ShareFlow provided the structure for these criteria to be met. It was this justification of ideas that was focused on more specifically in this phase of the research.

Background literature informing the use of Web 2.0 technology in education, in this instance ShareFlow, as a pedagogical tool for developing understanding of the NOS, was drawn from research on the use of Web 2.0 to enhance feedback; Web 2.0 to develop a community of practice; and Web 2.0 as a tool for developing collective cognitive responsibility. For each of these educational purposes, ShareFlow was evaluated positively.

Analysis of the students’ postings on ShareFlow showed that the ShareFlow platform provided ample opportunity for the students to give and receive feedback as their ideas about NOS developed. In the previous research phase, GoogleWave had been found to be effective as an approach for feedback. In this fourth phase of the research, feedback was extended in that rather than students focusing on individual posts when they observed NOS ideas, as with Google Wave, this second phase encouraged students to respond to the posts of others by critiquing, questioning and making comments—all to improve the expressed ideas about NOS. Since student thinking was consistently visible, in the form of posts, it was possible for the teacher, or increasingly for the students themselves, to provide information to fill the gap between what was understood and what was aimed to be understood (Sadler, 1989). It was interesting to note that the students themselves increasingly adopted this role, effectively increasing the opportunity for feedback to students beyond what a teacher alone could provide. ShareFlow enabled formative feedback to be provided in a seamless, ongoing manner throughout each session.

Students posting their own ideas, commenting on the ideas of others, receiving and giving feedback, all contributed to developing the community of practice (COP) of these students. The COP view of
learning is that learning is not exclusively a mental act but rather is also a social act, set in a participatory social context and dependent upon interaction among people and their tools and technologies (Lave, 1996; Rogoff et al., 1995; Wenger, 1998). Thus, in this phase of the research, the quality of the tool was found to be critical to the quality of the interaction. ShareFlow was identified as a quality interface within a socio-technical interaction network (Kling, McKim, & King, 2003).

Scardamalia and Bereiter’s (2003a) knowledge forum and knowledge building pedagogy extends this pedagogy of COP further by proposing that individuals within a knowledge building community are not just sharing knowledge, but are using their own and the ideas of others to construct a collective understanding and, yet further, to create knowledge. Analysis of all the ShareFlow posts consistently demonstrated sociocognitive and technological determinants of knowledge building (Scardamalia, 2002), such as treating ideas as improvable, assuming epistemic agency, producing ideas of value to each other and sharing responsibility for overall knowledge advancement of the community.

Scardamalia and Bereiter (2006) propose six themes of knowledge building. Their theme on knowledge of in contrast to knowledge about was considered to be particularly relevant in this research because it relates strongly to preservice teacher education and the translation of NOS understandings into practice. Analysis of the ShareFlow posts showed that using ShareFlow provided an ongoing platform for this community of learners to individually recognise and jointly share their growing knowledge about NOS, in recognising the opportunities for NOS teachable moments they noticed in the sessions, and in extending their discussion within ShareFlow to opportunities to teach NOS in their own classrooms.

It addressed the need for preservice teachers to continually be mindful of and to recognise the plethora of opportunities any science session has to teach NOS. For the preservice teachers, this knowledge about NOS could potentially enable them to use their NOS knowledge so that it becomes functional: functional for them as teachers in knowing why, when, how and what NOS to teach for functional and critical scientific literacy, and from this to devise appropriate learning experiences for their students; and functional in due course for the students they teach in enabling them to engage with science, see science as relevant, and use their NOS knowledge to address SSIs. The students’ postings show that increasingly over the duration of the course, they were able to recognise a NOS idea, relate it to the content being covered, but then also suggest other relevant contexts or SSIs to which this NOS idea could be related – to recognise the myriad of opportunities to see NOS in action.

The key findings of this phase of the research were that the use of Web 2.0 facilitated the shifting of emphasis away from the individual student’s acquisition of a deeper understanding of NOS to a collective cognitive responsibility within the class, a joint enterprise in which class members made contributions and recognised NOS ideas as being improvable objects. Web 2.0 provided a platform
which made visible the thoughts of students, and allowed multiple and repeated opportunities for reflection and for repeated and persistent opportunities for feedback on ideas about NOS. This feedback was multidirectional: from the student to the lecturer; from the lecturer to the students; from the students to each other. Finally, Web 2.0 facilitated a shift in students’ learning from knowledge about a handful of NOS tenets to knowledge of the richness of opportunities for NOS teaching and learning in a classroom environment.

This translation into practice became the focus of the final phase of research reported in this study.

**The fifth phase**

The participants in the final phase of this research were a cohort of University graduates \( n = 145 \) enrolled as preservice primary school teachers in the one year Graduate Diploma of Teaching (Primary Specialisation). The two major goals of the course were to develop preservice teachers’ understanding of contemporary views about NOS, and to build their ability to translate these views into effective teaching practice during the course, with the view that this would later mediate translation into their own classrooms. The intervention in this research phase, informed by the previous phases, was two-fold. The first was to integrate into the preservice teacher education course those curricular and instructional elements evidenced by research literature, and by previous phases in this study, as being effective in developing more robust NOS conceptions among preservice teachers. These elements included the use of: explicit NOS instruction; decontextualised NOS activities; contextualised embedded NOS instruction; historical and contemporary case studies; metacognitive learning strategies; a conceptual-change framework; and repeated opportunities for on-going reflection via a Web 2.0 platform.

The second intervention in this phase was to develop the PCK (Shulman, 1987) required for translation of selected dimensions of NOS into practice. This was researched by incorporating into the course NOS-inclusive lesson planning, peer teaching and microteaching. It was the effectiveness of peer teaching and microteaching to mediate the translation of NOS views into practice that was reported in this phase of the research. To date the research phases had reported on the development of content knowledge of NOS. This phase shifted the focus to the development of *pedagogical* content knowledge. Data were gathered from lesson plans for peer teaching and microteaching, self-evaluation of peer teaching and microteaching sessions, the Science Teacher Efficacy Belief Instrument (STEBI-B) and the preservice teachers’ evaluations.

It is acknowledged that the translation of a teacher’s conception of NOS into classroom activities and, thereby, into students’ understanding of NOS is a complex process. Previous research has reported a variety of personal and contextual factors as mediating or constraining the translation. Shulman (1987) posited that the development of teacher knowledge involves a dramatic shift in teacher thinking from a
professional understanding of science content to an awareness of new ways in which topics, problems, issues, and subject matter content can be represented, organised, and adapted to engage students in learning science. It follows that possessing a robust understanding of NOS is a necessary but insufficient condition for effective NOS teaching (e.g., Bell et al., 2011) – just as holding extensive substantive knowledge will not necessarily ensure effective teaching of science content. Effective teachers are those who are skilled in transforming their own subject knowledge – in this research study, that is knowledge about NOS – into sequences of varied learning experiences that acknowledge what is known to be already familiar to learners, to help learners construct personal knowledge and accomplish shifts towards the target knowledge represented in curriculum documents (Taber, 2010). A course structure is needed that facilitates this.

To that end, this phase of the research used Magnusson et al.’s (1999) definition of PCK as comprising five components: knowledge of curriculum, knowledge of students’ understanding of science, knowledge of representations and instructional strategies, knowledge of assessment, and teacher orientation for science. Since self-efficacy is also required for teaching, Bandura’s (1977) four principal sources of efficacy expectation: mastery experiences, vicarious experiences, verbal persuasion, and physiological and affective states (Bandura, 1997) were also examined. It was argued that since the teaching of NOS, is both difficult and challenging, those preservice teachers who have high self-efficacy concerning NOS are more likely to translate their NOS understandings into practice than those preservice teachers with low self-efficacy concerning NOS teaching.

Based on research reports indicating that micro/peer teaching has generally been found to be an effective way of helping preservice teachers learn about and reflect upon effective teaching practice (e.g., L’Anson et al., 2003; Klinzing, 2002) and provides a worthwhile learning experience in a positive and enabling context (Fernández, 2010; Topping, 2005), this research study examined the effectiveness of peer teaching and microteaching to develop preservice teachers’ NOS PCK in their planning and teaching for NOS.

Analysis of the lesson planning showed that in their initial peer teaching lesson plans most of the students focused on science content rather than teaching through NOS. In contrast, in their microteaching lesson planning for children later in the course, all preservice teachers identified NOS-related achievement aims and objectives from the curriculum and the majority created appropriate NOS-related learning outcomes for their teaching session. Similarly, in their microteaching most were able to demonstrate, in their use of diagnostic assessments, their understanding of the need for knowledge of students’ understanding of NOS.

Data gathered indicated shifts in each of Magnusson et al.’s, (1999) five dimensions of PCK. Most notably for this research was the shift seen in orientation for teaching – towards teaching NOS within
a context related to the students’ real life worlds or related to socioscientific issues. Similarly in their self-evaluations of their teaching, many of the preservice teachers showed a shift from comments indicating a technical or practical understanding of NOS teaching, to comments reflecting a well-contextualised, relevant, socioscientific embedded teaching and learning of NOS.

Regarding findings related to self-efficacy to teach science, direct comparison of preservice teachers’ self-efficacy in peer teaching with self-efficacy in microteaching is complicated by a multiplicity of variables, however, self-efficacy over the duration of the course as evidenced by the repeated STEBI-B (Enochs & Riggs, 1990) did indicate an increase in reported self-efficacy from pre-course to post-peer teaching, and again to post microteaching. Therefore it is proposed that peer teaching and microteaching provided opportunities for preservice teachers to develop self-efficacy to teach NOS. This demonstrated a shift from a focus on their learning and knowledge to a focus on student learning.

The usefulness of microteaching and peer teaching was further supported by the preservice teachers’ reported views on how they best learn: where the greatest increase in cohort mean from pre-course to post-course was seen in the two items “I learn from my peers” and “I learn from teaching others”.

These are useful findings, since limited content knowledge and PCK, and low self-efficacy have been linked to teachers avoiding science in the classroom, or teaching only within their comfort zone where they feel they can control the classroom (Appleton, 2006). Since PCK is developed through practice, through the act of teaching and thinking about it, it follows that to develop PCK, a science education course must include opportunities to practise teaching, including NOS, and to reflect upon that teaching. The key finding from this final phase of the research programme was that a preservice teacher education with an emphasis on microteaching and peer teaching can help develop preservice teachers’ NOS PCK and self-efficacy in a way that assists translation of informed NOS views into classroom teaching.

In addressing the first and second research questions, each of the five phases of the research have suggested that, consistent with the research literature (e.g., Akerson et al., 2006; Akerson & Hanuscin, 2007), teachers and preservice teachers generally do not hold informed understandings of NOS, regardless of their academic ability, academic background or teaching experience. To address the third and fourth research questions, factors which can contribute to positive shifts in NOS understandings, in PCK, and in the translation of these into lesson planning and teaching were examined. It can be seen that the complexity of the variables that lie within the learning processes confound the isolation of these factors in order to measure the respective impact of each factor (Kelly et al., 2008). However, the approach used has allowed the development of a better understanding of strategies that are effective and of the ways in which these impact NOS understandings, the development of PCK and of self-efficacy to teach NOS. These factors have included: explicit teaching of NOS; the use of generic
activities as analogies; the use of both decontextualised and contextualised instruction to enable the learners to move forwards and backwards along the continuum between them; the use of authentic contexts to deepen NOS understanding; structured opportunities for repeated reflection; the scaffolding of this reflection by harnessing the potential of Web 2.0; establishing a COP to foster knowledge building; the adoption of microteaching and peer teaching to develop PCK and self-efficacy; and the centrality of a metacognitive and learning-as-conceptual framework.

**Limitations of the study and suggestions for further research**

As a series of limited-sample case studies, the presented findings and conclusions cannot be used to generalise to other contexts. Rather, they serve as illustrative principles, strategies used, lessons learnt and results achieved to help inform the structure of teacher education science programmes. Furthermore, only one cohort of participants in this study were inservice teachers. It cannot necessarily be assumed that the findings from preservice teacher courses can be directly transferred to inservice teacher courses or professional development programmes. However, nor should it be assumed that they cannot be transferred.

Concerning translation into practice, this research has only evaluated two instances of practice – peer teaching and microteaching. It cannot be assumed that any translation evident in these two instances is indicative of the translation into first year (and subsequent) teaching. There are too many compounding variables. The presumed relationship between teachers’ conceptions of science and those of the students is too simplistic relative to the realities of classroom. However, there are important lessons embedded in these research findings for the development of teacher education programs, classroom practice and student learning.

Regarding directions for future research, it would be useful to examine to what extent the initiatives trialled in each of the iterative phases of this research are scaleable to other cohorts in initial teacher education. In particular, given the time constraints of preservice teacher education courses and of inservice professional development, further research should be conducted on the affordances provided by the use of Web 2.0 technology to develop NOS understanding.

It would also be useful to address more fully the durability of translation into practice by following a group of the preservice teachers into their first or second year of teaching. This would allow a longitudinal study focused on the ways in which the preservice emphasis on NOS PCK (including NOS in planning) translates (or not) into these teachers’ planning and teaching and their students’ learning. However, the research does provide good grounds for optimism in this respect.

In terms of NOS PCK, the smallest shift was seen in assessment of NOS, which is consistent with findings that teachers may lack sufficient knowledge of strategies for assessing students’ ideas about
NOS (Hanuscin et al., 2011). This also warrants further research.

Finally, it is worth highlighting that the present study contributes towards developing a philosophically and a pedagogically reasonable NOS curriculum. The theoretical claims need to be scrutinised and further refined, but also to be further tested empirically. The development of effective preservice teacher education programmes is an on-going, lengthy and complex process.

**Concluding Thoughts**

This conclusion opened with a quotation suggesting that the chief purpose of education is that “all who are involved should transform their capacities to act, think, and feel in ways that contribute to the common good and enrich their own lives” (Wells, 2001, p. 1). Since critical scientific literacy is concerned with the advancement of common good and also personal growth, it follows that preservice science teacher education should be transformative. This is a lofty, but achievable, goal.

In the journey of this thesis there have been three quotations which have been lightbulb moments. I would like to conclude the thesis with those quotations. Together, they comprise a personally satisfying conclusion to the thesis.

The first is from John Locke’s (1689) *Essay Concerning Human Understanding*:

> The floating of other men’s [sic] opinions in our brains makes us not one jot more knowing, though they happen to be true. What in them was science is in us but opinionate, whilst we give up our assent only to reverend names, and do not, as they did, employ our own reason to understand those truths which gave them reputation. Such borrowed wealth, like fairy money, though it be gold in the hand from which he received it, will be but leaves and dust when it comes to use. (1690/1924, p. 40)

Reading this challenged me to realise that a transmission mode of teaching, on NOS, would be mere ‘borrowed wealth’ and ‘fairy money’ to my students who received it. I was challenged to find ways to transfer epistemic agency to students and to engage them fully in meaningful communities of practice to reflect upon and collectively build their own ideas of NOS.

When intimidated by the enormity of the challenges and the brevity of the teacher education course, I remained spurred by Matthews’ exhortation to modest goals:

> It is unrealistic to expect students, or trainee teachers, to become competent historians, sociologists or philosophers of science. … Teachers should aim for a more complex understanding of science, not a total, or even a very complex, understanding. Fortunately philosophy does not have to be artificially imported to the science classroom, is not far below the surface in any lesson or textbook. … There is no need to overwhelm students with ‘cutting-edge’ philosophical questions. They have to crawl before they can walk, and walk before they can run. This is no more than commonsensical pedagogical practice (Matthews, 2012, p.21).
Finally, when doubts assailed as to the merits of ‘adding’ NOS to the science curriculum, I was profoundly encouraged by Hodson’s persuasive communication of the necessity for scientific literacy with its core understanding of NOS:

In short, why does it matter what image of science is presented and assimilated [in schools]? It matters insofar as it influences career choice, and so may have long-term consequences for individuals. It matters if the curriculum image of science is such that it dissuades creative, non-conformist and politically conscious individuals from choosing to pursue science at an advanced level. It matters if the image of science is such that it dissuades women, members of visible minority groups and students from lower socioeconomic status homes from entering science-related careers or seeking access to higher education in science and engineering because they do not see themselves included and represented in the science curriculum. It matters if our politicians, public servants and industrialists are so ignorant of scientific and technological issues that their decision-making is ill informed and uncritical. It matters if the general population is unable to respond logically and critically to the claims and proposals of those in society who might use scientific arguments (and sometimes pseudoscientifically spurious arguments) to persuade, manipulate and control. It matters if a significant part of humankind’s cultural achievement is poorly understood. Failing to provide every student with an adequate understanding of the nature of science runs counter to the demand for an educative citizenry capable of responsible and active participation in a democratic society. (Hodson, 2009a, pp. 142–143)
Appendices

Appendix A: Course Overviews

Included here are the calendar prescriptions and learning outcomes from two of the courses in this research. These are indicative of the courses in each of the five research phases.

Graduate Course

Calendar Prescription:
Develops an appreciation of the nature of science that supports conceptual understandings and quality teaching and learning approaches in science education. Addresses questions such as: How do teachers design quality learning environments based on the science curriculum so that positive engagement and effective learning can occur for a diverse range of learners? How is achievement determined and monitored?

Learning Outcomes:
At the completion of this course, it is intended that students will be able to:

- Evaluate and utilise assessment information and research literature about children’s learning in science and the nature of science, when planning and teaching science-rich experiences.
- Demonstrate understanding of science subject knowledge and pedagogy to create a supportive learning environment.
- Demonstrate knowledge of curriculum specific requirements and conventions related to planning for effective science learning and teaching for diverse learners.

Undergraduate Course

Calendar Prescription:
Develops an appreciation of the nature of science that supports conceptual understandings and quality teaching and learning approaches in science education. Addresses questions such as: How do teachers design quality learning experiences based on the science curriculum so that positive engagement and effective learning can occur for a diverse range of learners? How is learning monitored and assessed?

Learning Outcomes:
At the completion of this course, it is intended that students will be able to:

- Demonstrate an appreciation of the nature of science that underpins learning in science.
- Explain selected scientific concepts relevant to teaching.
- Design effective and engaging learning experiences for a diverse range of learners based on the curriculum.
- Monitor and assess learning in science.

**Table A1 Indicative Course Outline – Graduate Programme**

<table>
<thead>
<tr>
<th>Context / Curriculum Strand</th>
<th>Focus areas</th>
<th>Pedagogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter Matters</td>
<td>States of matter, Physical &amp; chemical properties, Physical &amp; chemical change, Nature of Science (NOS)</td>
<td>Importance of prior ideas, Diagnostic assessment, Using curriculum documents, Approaches – e.g. POE (Predict Observe Explain), Contextualisation (&amp; socioscientific issues), Using curriculum documents, NOS</td>
</tr>
<tr>
<td>(Material World strand)</td>
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<td></td>
</tr>
<tr>
<td>Living Life</td>
<td>Living / Non-living, Plants / Animals, Classification, NOS</td>
<td>Importance of prior ideas, Diagnostic assessment, Using curriculum documents, Investigations - asking answerable questions, Approaches – transmission approach, Integrating the Māori way of knowing, NOS</td>
</tr>
<tr>
<td>(Living World strand)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geology Rocks</td>
<td>Earth structure, Plate tectonics, Continental drift, Rock cycle, Rock classification, NOS</td>
<td>Importance of prior ideas, Diagnostic assessment, Using curriculum documents, Effective use of models, Different teaching approaches – theory &amp; practice, Formative &amp; summative assessment, NOS</td>
</tr>
<tr>
<td>(Planet Earth &amp; Beyond strand)</td>
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<tr>
<td>Looking Up</td>
<td>Sizes in space, Day &amp; night, Seasons, Eclipses, NOS</td>
<td>Importance of prior ideas, Diagnostic assessment, Using curriculum documents, Effective use of ICT, Effective use of models, Assessment, Literacy and drama, NOS</td>
</tr>
<tr>
<td>(Planet Earth &amp; Beyond strand)</td>
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<tr>
<td>Energised</td>
<td>Energy, Energy transformations, Sound &amp; light energy, NOS</td>
<td>Importance of prior ideas, Diagnostic assessment, Effective use of models, Simulations, NOS, Classroom strategies, Sequencing activities</td>
</tr>
<tr>
<td>(Physical World strand)</td>
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Appendix B: Brief description of the generic science-content-free activities used in the research

Chambers (1983) ‘Draw a Scientist’ and five of the generic science-content-free activities designed by Lederman and Abd-El-Khalick (1998) to model an explicit approach to teaching crucial aspects of the NOS were used in this research. Each of the activities will be described briefly in this Appendix. Full instructions for their use can be found in Lederman and Abd-El-Khalick (1998) and Chambers (1983).

**Draw a Scientist Test**

Children's illustrations have long been accepted as their representation of how they view the world. Student perceptions of scientists were first measured by Chambers (1983) in the original Draw-A-Scientist-Test (DAST), which was developed as an open-ended projective test to provide information regarding children’s perceptions of scientists. Modifications to this original test can ask the student to ‘Draw a scientist at work’ or ‘Imagine that tomorrow you are going on a trip (anywhere) to visit a scientist in a place where the scientist is working right now. Draw the scientist busy with the work this scientist does. Add a caption, which tells what this scientist might be saying to you about the work you are watching the scientist do’ (Farland-Smith, 2012).

In this research, the students were asked to ‘draw a scientist at work’. The students’ drawings were analysed as a class activity according to criteria such as:

- characteristics of individual carrying out the science, (white male, female, minority group etc.)
- the overall appearance of scientists (crazy, mad scientist, normal-looking, glasses, facial hair etc.)
- the location the scientist is in (basement, laboratory, etc.)
- the activity being done (mixing chemicals, studying rocks, finding fossils)
- the tools being used (from explosives to more commonly used tools such as magnifying glasses)
- symbols of knowledge (scientific formulae etc.)

It was stressed that such images may not necessarily accurately represent a student’s view of a scientist, but rather a) what the student is able to draw b) the stereotype they consciously choose to draw or c) that which readily springs to mind.

**Tricky Tracks!**

This activity is designed to help students make the distinction between observation and inference, and to appreciate the tentativeness of scientific knowledge and the role of creativity in science. Using a data projector the students are shown four images, which appear to be of bird tracks in a series of
different scenarios. They are asked to ‘describe what they observed’. In fact the only valid observation would be one such as that there are two sets of black marks of different shapes and sizes on the screen – generally all other explanations offered by the students are inferences rather than observations.

That’s Part of Life!
The ‘That’s Part of Life’ activity addresses the myth that all scientists are objective. The students are given a short and cleverly written, 200-word text that describes the process of doing the laundry. Because of the way in which it is written, very few students make sense of the text – until they are told that it describes doing the laundry. The analogy can be drawn to scientists not making sense of data unless they have existing theories and ideas. This runs counter to the generally accepted view of scientists as purely objective and observing with a blank mind. As an analogy it highlights that scientist' beliefs, previous knowledge, training, experiences, and expectations all affect how they do their work. Such background factors create a mindset which influences what the scientist observes and does not observe, and affects how they interpret their observations.

The Hole Picture
For this activity, a set of coloured random shapes is glued to a sheet of A4 paper which is then inserted into a manila folder, the front cover of which has had many small holes made in it. The sides of the manila folder are taped shut. Portions of the coloured shapes are visible through the holes. A sheet of clear overhead transparency is placed on top of the manila folder. The students are instructed to figure out the shapes and, without removing the inserts, trace their proposed shapes on the overhead transparency. The only available information to the students is what they see of the coloured paper through the holes.

The purpose of this activity is to present the analogy of scientists in their work who confronted with a natural phenomenon (the insert), pose certain questions to which there usually are no readily available answers - just as the students faced the question of the shape of the coloured pieces of paper on the insert. It is not often that scientists handle the phenomena first hand. Astrophysicists, for example, have produced scientific knowledge about the inside of the sun and the kinds of reactions taking place within, all without opening the sun to have a look inside.

The holes represent the empirical data scientists collect. Two parameters of data can be illustrated using this activity; amount and quality. The number of holes is analogous to the amount of data scientists can collect. The size of the holes (small vs. large) can represent the quality of the data.
Technology is a factor that can improve the quality of data – e.g. the naked eye as compared with a telescope for astronomers. The intention of this activity is to reinforce the difference between observation and inference, and to make explicit the creativity required in science.

The Aging President
In this activity the students are shown a series of caricatures of President Regan as he ages from the beginning to the end of his term in office. The students observe the caricatures and describe the changes that took place as the president aged. Usually, it will not be until the middle of the series that students start to note something other than Regan’s face, but may still not ‘see’, the female figure instead of Reagan’s face. The activity gives students a feel of what it means to approach a phenomenon with a certain paradigm or mindset or perspective. Even though certain facts change, a paradigm lingers on and sets expectations causing us to see what we expect to see.

This activity can serve as an analogy to paradigm shifts in science. Generally scientists do not readily give up the prevailing perspective (analogous to the drawing of a face) even if evidence to the contrary is available to them (analogous to the embedded image of the woman). It usually takes dramatic evidence, over a relatively long period of time before scientists exchange the old views for new ones. History is replete with instances of this. In this course the heliocentric solar system and the theory of continental drift were used as illustrative examples.

Young and Old
In this activity an image of a woman’s face is presented to the students via the data projector. Some students see an old woman; others see a young woman; a few can see both. The students are asked how it can be that they are all looking at the same image, yet seeing totally different pictures. The analogy is that scientists may look at the same piece of evidence or set of data and see different things. A scientist’s training, previous knowledge and experiences dispose him/her to ‘see’ a certain set of evidence from a certain perspective. In the same manner that the students were not able to see the face of the young lady in the drawing, scientists sometimes fail to ‘see’ (or perceive of a certain set of evidence as relevant to their questions.
Thinking about Science …………. 

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. Scientists produce scientific knowledge. Do you think this knowledge will change in the future? Why/why not?

3. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

4. After scientists have developed a scientific theory (e.g., the theory of an atom, or the theory of evolution), does the theory ever change?  
   YES                                    NO  
   Can you explain why/why not and defend your answer with examples.

5. What is an experiment?

6. Does the development of scientific knowledge always require experiments?  
   YES                                    NO  
   Give an example to defend your position.

7. Scientists carry out investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?  
   YES                                    NO
If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why scientists use imagination and creativity. Can you provide an example?

If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

8. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

Explain what you think.

Appendix D: Evaluation of ShareFlow

Please provide us with feedback on the use of ShareFlow in this course, by completing the questionnaire below. Thanks in anticipation.

<table>
<thead>
<tr>
<th>Dimension: Engagement</th>
<th>Never</th>
<th>Almost Never</th>
<th>Occasionally</th>
<th>Almost Always</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>I feel more involved in class because we use ShareFlow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading, thinking on (and responding) to posts and feedback improves my attention</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ShareFlow reduces my anxiety in understanding NOS content</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>The quality of the ShareFlow posts increases my level of engagement</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Provides a forum for sharing ideas virtually</td>
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<td></td>
<td></td>
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<tr>
<td>Fosters discussion of ideas face-face</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allows access beyond class time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimension: Learning</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>ShareFlow facilitates explicit teaching and learning about NOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ShareFlow makes me aware of prior knowledge of NOS ideas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The use of ShareFlow contributed to my understanding of NOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viewing posts and feedback helps me assess (ongoing) my own understanding of NOS</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>It allows the ideas of others to be seen</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It allows for the improvement of ideas about NOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allows for the collective building of ideas about NOS</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

| Dimension: Student interaction | | | | | |
|-------------------------------|---|---|---|---|
| ShareFlow helps me communicate better with other classmates in this course | | | | |
| ShareFlow helps me communicate better with the lecturer in this course | | | | |
| I learn from the feedback/replies to others’ posts | | | | |
| I learn from the feedback/replies to my posts | | | | |
| It encourages a stronger collegiality within the class | | | | |
| It supports group work, and discussions | | | | |

| Dimension: Technology | | | | | |
|-----------------------|---|---|---|---|
| The ShareFlow interface is easy to use | | | | |
| I can see my posts and the posts of others quickly | | | | |
| The technology is not intrusive or disruptive | | | | |
| The technology is a hindrance to interaction | | | | |
| The technology increases the possibility of becoming side-tracked or distracted | | | | |
| This is a type of use of technology I would want to use in my own teaching practice | | | | |
Appendix E: New Zealand Curriculum (2007) Achievement Aims and Achievement Objectives for the Nature of Science Strand

<table>
<thead>
<tr>
<th>Achievement aims – Levels 1-8</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding about science</strong></td>
<td>Carry out science investigations using a variety of approaches: classifying and identifying, pattern seeking, exploring, investigating models, fair testing, making things, or developing systems.</td>
</tr>
<tr>
<td><strong>Investigating in science</strong></td>
<td>Develop knowledge of the vocabulary, numeric and symbol systems, and conventions of science and use this knowledge to communicate about their own and others’ ideas.</td>
</tr>
<tr>
<td><strong>Communicating in science</strong></td>
<td>Bring a scientific perspective to decisions and actions as appropriate.</td>
</tr>
<tr>
<td><strong>Participating and contributing</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 1 and 2 – Achievement objectives</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding about science</strong></td>
<td>Extend their experiences and personal explanations of the natural world through exploration, play, asking questions, and discussing simple models.</td>
</tr>
<tr>
<td><strong>Investigating in science</strong></td>
<td>Build their language and develop their understandings of the many ways the natural world can be represented.</td>
</tr>
<tr>
<td><strong>Communicating in science</strong></td>
<td>Explore and act on issues and questions that link their science learning to their daily living.</td>
</tr>
<tr>
<td><strong>Participating and contributing</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 3 and 4 – Achievement objectives</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding about science</strong></td>
<td>Build on prior experiences, working together to share and examine their own and others’ knowledge. Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations.</td>
</tr>
<tr>
<td><strong>Investigating in science</strong></td>
<td>Begin to use a range of scientific symbols, conventions, and vocabulary. Engage with a range of science texts and begin to question the purposes for which these texts are constructed.</td>
</tr>
<tr>
<td><strong>Communicating in science</strong></td>
<td>Use their growing science knowledge when considering issues of concern to them. Explore various aspects of an issue and make decisions about possible actions.</td>
</tr>
<tr>
<td><strong>Participating and contributing</strong></td>
<td></td>
</tr>
</tbody>
</table>
### Level 5 and 6 – Achievement objectives

<table>
<thead>
<tr>
<th>Understanding about science</th>
<th>Understanding about science</th>
<th>Understanding about science</th>
<th>Understanding about science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand that scientists’ investigations are informed by current scientific theories and aim to collect evidence that will be interpreted through processes of logical argument.</td>
<td>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.</td>
<td>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).</td>
<td>Develop and carry out investigations that extend their science knowledge, including developing their understanding of the relationship between investigations and scientific theories and models.</td>
</tr>
</tbody>
</table>

### Level 7 and 8 – Achievement objectives

<table>
<thead>
<tr>
<th>Understanding about science</th>
<th>Understanding about science</th>
<th>Understanding about science</th>
<th>Understanding about science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand that scientists have an obligation to connect their new ideas to current and historical scientific knowledge and to present their findings for peer review and debate.</td>
<td>Develop and carry out investigations that extend their science knowledge, including developing their understanding of the relationship between investigations and scientific theories and models.</td>
<td>Use accepted science knowledge, vocabulary, symbols, and conventions when evaluating accounts of the natural world and consider the wider implications of the methods of communication and/or representation employed.</td>
<td>Use relevant information to develop a coherent understanding of socio-scientific issues that concern them, to identify possible responses at both personal and societal levels.</td>
</tr>
</tbody>
</table>
Appendix F: Permissions to include published work

Re Chapter 4 Realising the Potential of an Authentic Context to Understand the Characteristics of NOS and NOT: You, Me and UV:

From: Rena Heap
To: Editor_IJSE@hotmail.co.uk
CC: b.france@auckland.ac.nz; d.hodson@auckland.ac.nz; ms.stephenson@auckland.ac.nz
Subject: Seeking permission
Date: Mon, 10 Feb 2014 12:17:07 +0000

Dear John,

I am about to submit my PhD for examination. Under the University of Auckland 2011 doctoral statutes, students may include published and/or submitted papers in the doctorate. These can be sole or co-authored. There are many regulations concerning this, one of which is that I need Bev's consent as a co-author (which she has kindly given) and yours as editor of the journal in which the article was published.

So I email you to seek permission to include in my doctorate:


Of course this would be with full acknowledgement of Bev and of IJSE, yourself as editor.

Kindest regards,

Rena Heap

Rena Heap
School of Curriculum and Pedagogy
Faculty of Education
University of Auckland
Gate 3, 74 Epsom Ave, Epsom
Private Bag 92601, Symonds St, Auckland
New Zealand
Ph.: +649 623 8899 ext. 48636
Email: r.heap@auckland.ac.nz

From: John Gilbert [editor_ijse@hotmail.co.uk]
Sent: Tuesday, 11 February 2014 11:27 p.m.
To: Rena Heap
Subject: RE: Seeking permission

Dear Rena,

Of course I remember you!

Yes, you have my permission to include that paper in your thesis.

Good luck with the examination.

John Gilbert

Publisher:

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From: Rena Heap
Sent: Thursday, 13 February 2014 8:11 a.m.
To: David Ellis
Subject: Seeking permission

Dear David,

I am about to submit my PhD for examination under the University of Auckland 2011 doctoral statutes which allows the inclusion of published and/or submitted papers in the doctorate. There are many regulations concerning this, one of which is that I need to obtain consent. So I am emailing you to seek permission to include as one of the published articles in my doctorate:


Of course this would be with full acknowledgement of the editors and NZCER Press and with full reference to the published monograph. All three editors have sent their consent - as attached below.

Thank-you for your consideration of this. I am more than happy to send you any further information you need.

Kindest regards,
Rena Heap

Rena Heap
School of Curriculum and Pedagogy
Faculty of Education
University of Auckland
Gate 3, 74 Epsom Ave, Epsom
Private Bag 92601, Symonds St, Auckland
Ph.: +649 623 8899 ext. 48636
Email: r.heap@auckland.ac.nz

From: Stephen May
Sent: Thursday, 13 February 2014 8:03 a.m.
To: Rena Heap
Cc: Judy Parr; Helen Hedges
Subject: Re: Seeking permission

No problem with me (& congratulations)!
Stephen

From: Helen Hedges
Sent: Thursday, 13 February 2014 7:57 a.m.
To: Rena Heap
Cc: Judy Parr; Stephen May
Subject: Re: Seeking permission

This is wonderful news Rena and of course you have my permission.
Warm regards
Helen

Sent: Thursday, 13 February 2014 7:23 a.m.
To: Rena Heap
Cc: Helen Hedges; Stephen May
Subject: Re: Seeking permission

No problem from my end but does it require publisher approval?
Judy
Hi Rena,

Thanks for getting in touch re permission - that is absolutely fine to use the article.

Best wishes

David

Re Chapter 3_Structuring Reflection to Develop an Understanding of the Nature of Science:

In accordance with Guideline 2a of The University of Auckland 2011 Statutes and Guidelines for the Degree of Doctor of Philosophy (2013), it is noted that this chapter draws from data in my Masters’ thesis, Myth Busting and Tenet Building (Heap, 2007), extends the analysis, findings and theorising of the work, and was completed while under doctoral supervision.
References


Dawes, J. (2008). Do data characteristics change according to the number of scale points used? An experiment using 5 point, 7 point and 10 point scales. International Journal of Market Research, 50(1), 61-77.


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Taber, K. S. (2012). The natures of scientific thinking: Creativity as the handmaiden to logic in the development of public and personal knowledge. In M. Khine (Ed.), Advances in nature of science research (pp. 51–74). Netherlands: Springer.


