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Ontological possibilities for rethinking teaching of the “nature of science”

by

Rosemary Hipkins, B.Sc (Hons), M.Ed

Submitted in fulfillment of the requirements for the degree of

Doctor of Philosophy

Deakin University

August 2006
I certify that the thesis entitled: Ontological possibilities for rethinking teaching of the “nature of science”

submitted for the degree of Doctor of Philosophy

is the result of my own work and that where reference is made to the work of others, due acknowledgment is given.

I also certify that any material in the thesis which has been accepted for a degree or diploma by any university or institution is identified in the text.

Full Name.......................................................... Rosemary Hopkins
(Please Print)

Signed ....................... ........................................

Date................................. 19 December 2006

Signature Redacted by Library
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Abstract

An extensive literature documents teachers’ failure to include ideas about the “nature of science” (NOS) in their classroom programmes, despite widespread advocacy for this as an essential component of more inclusive science teaching. This thesis frames much of the existing NOS literature as a deficit literature that focuses on epistemology, while largely ignoring the ontological realities of the classroom and overestimating individual teacher’s agency to change their enacted curriculum. Epistemologically-focused NOS reforms are positioned as curriculum “add-ons”, which teachers are likely to ignore. A NOS focus on ontology would entail curriculum restructuring, attending first to the contexts in which scientific knowledge is produced, and the ways it acts in the world.

In any case, science itself has changed in recent years. Drawing from the sociology of science, in particular the work of Bruno Latour, the thesis compares traditional philosophical thinking about the ontology of science with more recent “networked” views. Brent Davis explains the educational implications of key ideas from complexity science. Political philosopher Stephen White adds an ethical dimension. His ideas are used to argue for replacing “strong” ontologies of realist science with more nuanced and actively tended “weak” ontologies, as appropriate to the rapid sociological changes of the twenty-first century.

The thesis argues that epistemological uncertainties that could lead to the suspicion of relativism are potentially threatening in the classroom because of hegemonic pressures towards consensus and a certain, safe status for the knowledge taught. Seeking an alternative pathway to change, Daniel Liston’s conceptualisation of teaching as a passionate act informs the analysis of the empirical component of the thesis. Eight recipients of New Zealand Royal Society Science Teacher Fellowships were interviewed on four occasions over two years. They discussed their personal learning during a year-long sabbatical to carry out an extended science investigation and their thoughts and actions on returning to the classroom. Narrative methodology is used to explore the teachers’ stories, revealing both passion for their personal learning and an ethical concern for their students’ learning to care for both the natural world and science as a means of its investigation.
The thesis argues for the use of ontological approaches to the initial introduction of NOS ideas in school science, with epistemological concepts added only once a topic has been grounded in what Latour calls “matters of concern”. Two potential teaching strategies—the production of network diagrams and the use of Davis’ \textquoteleft{bifurcations’} as a critical inquiry tool—are the focus of hypothetical experimentation. First in the context of global warming, and then addressing the challenges posed to teaching evolution by the proponents of \textquoteleft{intelligent design’}, these strategies are shown to have the potential to address some of science education’s thornier issues, not just the NOS question.

However, when conflicting expectations create tensions for teachers in the classroom moment, it is difficult for them to introduce reflective, deeply philosophical changes to their representation of science. Their working realities need to be acknowledged, and the tensions ameliorated, if we expect substantive change in their current practice.
1. Outline of a personal learning journey

For just over 20 years I was a typical classroom teacher, passionate about science, doing my best to engage my students and support their learning success. I had completed a science degree with honours in the late 1960s, specialising in genetics, and teaching biology was my great interest. It was not until my Master of Education studies, completed during the 1990s, by which time I was working as a teacher educator, that the world of philosophy opened up for me. I learnt about the “nature of science”, or NOS, for the first time, and could immediately see how it would have made my classroom practice much richer, and solved some of my dilemmas—for example, the teaching of evolution to students in a conservative church-based school.

Notwithstanding the strength of my own new understandings, I found it almost impossible to make so much as a dent in the thinking of my ex-colleagues, or my student teachers, who took their cue from “real” teachers rather than me. In this, I came to realise, I was not alone. An extensive literature documents teachers’ failure to include ideas about NOS in their classroom programmes, despite widespread advocacy from science educators that this should be an essential component of science teaching that makes science relevant for all students, not just a science-minded elite. At the outset of my thesis I wanted to find a way to help science teachers engage with ideas that I could see would have been so liberating to my own teaching practice, but I was all too aware of the obstacles. I saw the thesis as my attempt to help find a way forward. I framed my initial question as:

What is the relationship between teachers’ views of the nature of science (NOS) and their willingness to embrace change in their classroom practice?

The thinking behind this question was primarily grounded in science education research that has a focus on teachers’ epistemological views about NOS. Stated briefly, this research field suggests that teachers’ naïve NOS views, formed over a lifetime of experiences, are largely implicitly held, and consequently difficult to change. I wondered if typical NOS views, identified in the research literature as

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1 For brevity, the thesis will refer to this by the common shorthand version as NOS. However, the quotation marks I have used are intended to signal that this is not necessarily a unitary or unproblematic idea, as will become obvious as the thesis unfolds.
empiricist and positivist, might mediate against embracing current reform initiatives that promote non-traditional goals for a school science education, with associated content reduction and refocusing, and the employment of different types of pedagogy. If this was the case, then opportunities to change NOS views as a result of new learning experiences might be accompanied by identifiable changes in classroom practice. At this beginning point in the research I saw the identification and description of any links between change in NOS understandings and change in classroom practice as the primary goal of the research.

**The evolving research question**

My research began in traditional fashion with a review of existing literature concerning NOS in relation to teaching. An overview of this journey is presented in Section 2, although key findings have already been incorporated into several collaborative publications (Hipkins, Barker & Bolstad 2005; Hipkins et al. 2002). For this thesis, an important outcome of the early years of my research was that I came to see much of the existing NOS literature as a deficit literature. I began to question the helpfulness of an almost exclusive focus on teachers’ lack of epistemological knowledge, and their seeming unwillingness to change this situation. I saw parallels between the assumptions embedded in this type of research and the critique of a deficit focus with regard to “topping up” students with science content (see, for example, Layton, Jenkins, McGill & Davey 1993). Those who judge teachers’ work in this way typically say teaching has failed if students do not seem to know this, that, and the other thing. They may do so without any informed reference to the wider contexts of teachers’ work, or to the actual outcomes teachers seek to achieve (whether these are explicit or tacit). If we see this as unhelpful for achieving change in science education, why would we do the same thing with regard to the introduction of NOS into the curriculum?

New insights into the importance of the wider contexts of teachers’ work came with a shift in the focus of the thesis from epistemology to ontology. In the third year of my (part-time) study I had begun to immerse myself in several interrelated research fields that were new for me. These included pragmatism, actor network theory, and science studies, more recently known as the sociology of science knowledge (SSK) (see, for example, Law 2004). The focus of the science education literature, with its
almost exclusive emphasis on epistemology, had already begun to seem inadequate and now I discovered new ways to more constructively reframe my research question. My contradictory interest in, and unease with, post-modern theorising also began to make more sense. By this time, too, I had some initial empirical data on which to reflect. The result of all these influences was that my research question now became:

How do science teachers’ experiences of science, and their experiences of teaching, interact to produce their classroom practice?

Findings in relation to this question are outlined in Sections 5 and 6. In these sections I mostly employ a traditional ontological perspective that takes ontology to mean “being”. However in other parts of the thesis I take the more recent development of ontology as meaning “reality” (White, S. 2000), as I briefly outline below.

Establishing a causal link between NOS views and classroom change was always going to be problematic. I had left this indeterminate in the original proposal with the intention that the interview questions would evolve as response patterns began to emerge. With the insight gained from a pragmatic philosophical perspective, I came to see that the “problem” itself (classroom teachers’ seeming reluctance to embrace change to include NOS in their teaching practice) needed much more careful analytic description:

We should never accept problems as they present themselves. If we would do that, we would forget what makes certain occurrences into social problems is precisely the fact that they are intimately connected with certain aims, ends, purposes, ideals, and aspirations. This is not to suggest that all social problems can simply be solved by changing the human context in which they occur. It is only to remind ourselves that when we simply take the problems as they are, we do not allow ourselves the opportunity for ‘analytic discrimination’, which is one of the crucial activities in the transformation of an indeterminate situation into a problematic situation. This would lead to a situation in which the business of social inquiry would be restricted to finding the best method for solving problems as they present themselves, rather than trying to establish what the (social) problem actually is. (Biesta & Burbules 2003, p.77, emphasis added)

At this stage the challenge for the thesis became one of constructing rich descriptions of the interacting influences including, but not limited to, teachers’ NOS views on their decision making in the classroom moment. I had by now had several conversations in which my research participants spoke of these issues and
constraints. I understand the world my research participants occupy, although it is no longer mine, and so these comments evoked feelings and responses from me that I took seriously as “transgressive data” (St. Pierre 1997). I saw clearly that much existing NOS research took no account of the realities of the classroom and misrepresented (or at least overestimated) individual teacher’s agency to change their enacted curriculum. This thinking led me to an analysis of the impact of wider contexts of school and community expectations on teachers’ ability to affect change. I have reported this analysis elsewhere (Hippins 2005a) and have included a little of it in Section 8. However, I mainly chose to conserve the limited reporting space of the thesis for a final development in my thinking—one that pointed in the direction of a way forward, rather than simply illuminating the many obstacles to change.

**Ontology and the curriculum**

For the last five years I have been employed as a researcher at the New Zealand Council for Educational Research. As part of my paid employment I was invited in late 2004, by New Zealand’s Ministry of Education (MOE), to write a discussion paper related to their Curriculum Marautanga Project (a major national curriculum revision). The intended audience was health, home economics, and physical education teachers. The proposed discussion would demonstrate ways their forward-looking curriculum (of which I was one of the writing team in the late 1990s) had already anticipated challenges of teaching and learning for the twenty-first century, and ways they might move it still further forward.

In contracting this paper, the MOE explicitly requested a future-focused discussion. Accordingly, I introduced insights from my thesis journey concerning ontology and its impact on teachers’ work. A revised version was subsequently published in a newly established curriculum journal (Hippins 2005b). Comments from a blind reviewer of that article helped me to see what had hitherto been largely tacit in my thinking—that I was actually arguing for a significant change in the curriculum itself. This new insight gave me the courage to face squarely up to the following question:

*What might NOS look like in a curriculum that takes ontology into account, not just epistemology?*
I prepare the ground to address this question in Section 3, where I review various ontological positions that can be adopted when accounting for “reality”. I outline both traditional and future-focused philosophies, and briefly introduce ways that the latter might inform pedagogical change. Ideas in theory are one thing. Practical developments are quite another. Section 7 of the thesis models some ways these ideas might be brought into practice. However, to do so without taking account of teachers’ existing realities would be a betrayal of the rest of the thesis journey. Accordingly, what I propose in Section 7 is grounded in the findings of Sections 5 and 6, not just in the theory of Section 3.

**An overview of the empirical component of the thesis**

The thesis reports on aspects of a qualitative study that explored eight teachers’ personal constructions of the “nature of science”, and how these might play out in their teaching role. The science education literature suggests that the shaping and perpetuation of teachers’ positivist and empiricist NOS views may be linked to the lack of opportunities to experience actual scientific research during their own education and preparation to become teachers. At the outset of my research I identified a situation in which a group of primary and secondary teachers was being provided with just such an opportunity. They were to be the recipients of 2003 New Zealand Science Mathematics and Technology Teacher Fellowships.

These fellowships are competitive awards that pay for a small group of teachers each year to work, for that year, in a professional research setting, on an investigation of their own shaping, in one or a small number of institutions of their own choosing. The science fellows are hosted by one or more scientists, who help shape and guide the planned project. This is, however, a discrete project, over which the teacher/researcher has considerable autonomy. The teacher is not just “another pair of hands” although their project may be linked into a wider programme of work, just as a post-graduate student’s research could be organised. There are multiple goals for these fellowships. They include a “sabbatical” component, rewarding and refreshing hard-working teachers who are considered to have contributed much to their profession. They are also intended to raise the profile of science research and possible science careers in New Zealand, as the teachers shape educative materials based on their research experiences and subsequently share these experiences with
their students and with other teachers. The development of more realistic NOS understandings is not an explicit goal for the experience but I saw an opportunity to check suggestions in the literature that this could be an outcome of such learning experiences.

I decided to seek permission to work with some of the 2003 teacher fellows, with the aim of tracing links between their year of science learning and their subsequent classroom teaching upon their return to their schools. I hoped I would be able to elucidate the key factors that shaped the way they thought about their learning experiences in professional science in relation to their teaching of science. I realised that on their return to the classroom in 2004, the teachers might or might not change their classroom practice. Through ongoing discussions, I hoped to identify factors that seemed to have made the difference, including the possibility that improved understandings of NOS might be one such factor.

Once my plans had been approved by the ethics committee at Victoria University of Wellington (where my thesis began), I wrote to the Director of the Royal Society seeking his agreement to my project (see Appendix 1). This was granted. Near the end of the 2002 year all the recipients of 2003 Teacher Fellowships were brought together for an initiation day in Wellington. There were around 100 of them and they came from all over New Zealand. About half of the group (45) were science fellows. The others were mathematicians, technologists, and social scientists. The venue for much of the day’s activity was a large, noisy, wooden school hall across the road from the Royal Society’s offices. I had been promised a short time slot to meet with the science fellows to introduce my research and ask for volunteers. I went along armed with participant information sheets and acceptance forms (see Appendix 2), the latter to be returned to me in the self-addressed envelopes I also provided.

The day’s programme was already behind schedule when I arrived just before lunch. My promised half-hour shrunk to just five minutes and I was confronted with an oblong-shaped “circle” of science fellows in one corner of an echoing hall abuzz with the lively conversation of other groups. I felt like a laughing clown from a circus sideshow as I did my best to make eye contact and be heard by either extremity of the group, and to put my request over the background noise. The circumstances could hardly have been less propitious and I worried that I would get
no recruits at all. In the event, after some anxious days of waiting, eight teachers volunteered and returned agreement forms. Six were secondary teachers and two primary. Most were doing projects with a biological/environmental focus. One of these initial recruits must have changed her mind because subsequent communications from me went unanswered. However another participant unexpectedly volunteered early in 2003 and so the size of the group remained at eight.

The eight participants chose pseudonyms, by which they are identified throughout the thesis. The following profiles are necessarily brief, for New Zealand is small, the fellowships have a high profile, and I undertook to protect their identity.

Alice was a secondary school science and biology teacher. (She has subsequently left her school.) She has a strong interest in the environment and her research project addressed a conservation question.

Bridie is a primary school teacher with a strong interest in nature studies and the environment. Her research project also addressed a conservation question.

Halifax is a secondary school science and biology teacher. She investigated a question of importance in an agriculture/horticulture context, deliberately choosing an area in which she had little prior contextual knowledge.

Lesley is another secondary school science and biology teacher. Her project included both laboratory- and field-based components, including specialist DNA work.

Mark is a secondary school science and chemistry teacher. Like Halifax, he investigated a question of importance in an agriculture/horticulture context.

Ross is a primary school teacher with a strong interest in the environment. Like Bridie and Alice, his research project addressed a conservation question.

Sarah is another secondary school science and biology teacher. She also completed a project with a conservation focus.
Zoe, too, was a secondary school science and biology teacher. Like Alice, she has subsequently left the classroom. Her project concerned conservation and environmental education.

**Documenting participants’ learning journeys—the interviews**

Initially I was worried that the group was not sufficiently large, nor more widely representative of the diversity of science teachers as a whole. However as the research proceeded I realised that neither factor would actually be an obstacle because every participant’s learning journey was unique, and so richly textured that to cope with more people would have taken away from the depth with which these eight stories could be analysed and told.

The main method for gathering empirical data was planned as a series of interviews. However, some initial data was collected when, with each participant’s agreement, I was allowed access to their fellowship applications, held in the offices of the Royal Society. From these I gathered personal data (see Appendix 3) and initial insights into each participant’s thoughts about their goals for their fellowship year, as well as details of their proposed projects.

The timing of the interviews is shown on the timeline below, with the actual schedules included as Appendix 4. The methodology employed for their analysis is discussed in Section 4.

The timeline also shows a change of university during the course of my study. When my original supervisor was about to leave Victoria University of Wellington we discussed possible replacements, looking for potential new supervisors who would be interested in, and supportive of, the directions my research was taking. This led to my transfer to Deakin University for the remainder of my studies.

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2 I did not have a chance to gather this data for the eighth participant, recruited some time later.
The research timeline

2000  Conversations with potential supervisors
      Research problem identified as an extension of question explored in MEd
      Thesis (Hipkins 1998)

2001  Formal enrolment at VUW
      Reading year
      Change of occupation from teacher educator to researcher
      Science education literature review completed

2002  Small pilot of some possible research questions
      Formal proposal shaped, submitted, and approved
      VUW ethics approval sought and obtained
      Participants recruited

2003  Teacher fellowships begin late January
      First interviews conducted February—March
      Transfer to Deakin University completed and ethics approval reconfirmed
      Second interviews conducted September—October
      Paper written for IJSE, with two colleagues, partly based on thesis reading
      and partly on a literature review completed for NZCER

2004  Third round of interviews completed February—March
      Deakin University colloquium held on July 5
      Fourth round of interviews conducted October—November

2005  Data analysis completed and discussion of findings shaped
      Writing of thesis begun and interwoven with ongoing literature search
      Paper written for presentation at ASERA conference, Hamilton, NZ

2006  Completion and examination of written thesis
2. NOS in the school curriculum

This section discusses issues associated with teaching about the nature of science (NOS) as part of science education at the secondary school level. It is organised in five parts. The first part briefly outlines the scope and contested nature of what is meant by the term “NOS”. Next, various types of advocacy for NOS teaching are sketched. The third subsection explores what might be encompassed within aspects of the curriculum related to teaching about NOS. The fourth subsection introduces research literature that documents a persistent pattern of non-uptake of this aspect of school curricula to ask why NOS is rarely taught, at least as curriculum reformers intend that it should be. The final subsection frames this as a deficit literature and asks how issues for NOS teaching might be reframed to achieve more constructive outcomes for science education.

Multiple meanings for NOS

One objection to the use of the term the nature of science is that there is not one unified “nature” as the name suggests, but rather many ways in which scientific inquiry proceeds. Debates about the actual nature(s) of science tend to fall into two broad groupings.

Epistemological aspects

An epistemologically focused NOS concerns itself with the nature of the rational thinking processes involved in science, and in particular the nature of relationships between existing scientific theories and empirical evidence. These are hotly contested matters (see, for example, Chalmers 1982; Hoyningen-Hune 1993; Kuhn 1962) about which philosophers themselves do not agree (Alters 1997). Writing increasingly frequently for lay readers, historians of science document changes over time that demonstrate clearly that there is no one stable position that can ever be arrived at with respect to a unified view of NOS (for examples see Ruse 1999; Schwartz, J. 1992; Wertheim 1997). Nevertheless, a broad consensus on ways the epistemology of science should be presented in the school curriculum does now appear to be developing amongst science education researchers (Hipkins, Barker &
Sociological aspects

Sociological issues of science knowledge building are even more controversial than epistemological aspects. This is an area in which debate tagged the “science wars” still rages amongst philosophers (Labinger & Collins 2001). There is dissent about the manner in which different types of relationships impact on knowledge building processes, including relationships within science communities (Edmonds & Eidenow 2001; Latour & Woolgar 1979), and between scientists and the wider community (Latour 1999; Ruse 1999). The manner in which assumptions and core values of science invisibly shape those wider communities in return is also a subject of debate (Haraway 1989; Harding, S. 1991).

The NOS to which teachers tacitly subscribe

It is often claimed that teachers all around the world hold epistemological positions, at least tacitly, that are inductivist/empiricist (see, for example, Benson 1989; Gallagher 1991; Hodson 1988; Thoermer & Sodian 2002). Guy Claxton (1997) refers to the “widespread assumption that science does not just own the epistemological high ground, but is actually the only (valid) epistemological game in town, goes for the most part, unarticulated and uncontested” (p.75). Some say that this type of epistemology is typically combined with a strongly realist science ontology (Yore 2001). I find it interesting that aspects of both sociological and epistemological NOS debates have become increasingly entangled with discussion of ontology, and I return to these contested issues in more detail in Section 3.

Advocacy for NOS as a curriculum focus

Since the early twentieth century there has been continuing dissatisfaction with the state of science education at all levels of the school system, but in particular in secondary schools. During all this time the purposes for the inclusion of science in the school curriculum have been contested (DeBoer 1991; Nott 1997). Control over the goals and content of science curriculum has sometimes favoured the education of future scientists, and sometimes sought to make science more relevant to the lives of all students (DeBoer 1991). Some say that periodic cycling between these two very
different emphases has created false crises in education that have ensured ongoing funding and political support for “new” developments (see, for example, Klopfer & Champagne 1990).

When scientists have been more powerful in these debates, learning approaches have typically promoted the logical structure of science discipline knowledge as the appropriate focus for curriculum structuring and content selection (DeBoer 1991). However, some claim this has resulted in an “inauthentic science” where teachers present decontextualised science concepts in a manner that is consistent with a positivist philosophy of the nature of science (Gaskell 1992). Such a curriculum is experienced by students as an overwhelming body of content to be learned (Goodrum, Hackling & Rennie 2000; Osborne, J. & Collins 2000). This has been exacerbated by a “knowledge explosion” in science itself during the last two centuries, with more curriculum content continually added, and little correspondingly subtracted (Harding, P. & Vining 1997).

Since the 1980s there have been concerted calls for science education to become more broadly relevant for all students (for a typical recent example see Lemke 2005). In any case future scientists are also future citizens (Millar & Osborne 1998) so the one agenda could be seen as subsuming the other. Advocacy for a widely relevant “science for all” (Fensham 1985) may call for any or all of the following: the development of “scientific literacy”; more widespread use of “inquiry” learning approaches; adoption of a “science-technology-society” (STS) focus; and paying more attention to real examples of professional science.

Developing “science literacy”
Scientific literacy is broadly taken to mean being sufficiently comfortable with the big ideas and investigative processes of science to use this knowledge when relevant to decisions taken in adult life (Millar & Osborne 1998; Ryder 2001). There are a number of ways of interpreting this broad intention (Laugksch 2000) although these mostly involve a focus on the epistemological aspects of NOS. There is, however, considerable debate about whether learning science at school actually leads to the sort of knowledge transfer intended for the years beyond school (Duggan & Gott 2002; Lemke 2002).
Perhaps the most conservative interpretation of epistemological NOS goals is that theory/evidence links should be drawn during content learning. That is, students learn about the evidential warrants for the traditional curriculum knowledge they are being taught. Some claim that such learning about science as a knowledge-building process can lead to later “intellectual independence”. For example, Hugh Munby and Douglas Roberts (1998) describe this as an “implicit message” to the student that can be summed up thus:

You can learn to assess the truth and reasonableness of knowledge claims and explanations; you do not have to remain intellectually dependent on a teacher for such assessments. (Munby & Roberts 1998, p.102)

They claim that such independence of thought is fostered when teachers give students practice at making these types of judgements and that this requires teaching for certain types of epistemologically-focused learning experiences:

In the case of intellectual independence, students need to experience, repeatedly and consistently, such messages as that evidence is needed to support claims, that reasons and arguments are associated with claiming to know in science, that there are publicly acknowledged means for assessing the truth of claims, and - especially - that students can learn how to use this reasoning power. That is, the teacher needs to distribute the power inherent in these messages, to ‘let the students in on the secrets’ of how science works, rather than cloaking them. (Munby & Roberts 1998, p.105, emphasis in the original)

This is a big claim and it seems to me to potentially elide two very different types of knowledge—the so-called “canon” of relatively uncontested science theories and laws, and more contentious areas of active knowledge building. Why would students need to bring intellectual independence to knowledge that most, if not all, scientists accept as “true”? In the final section of the thesis I return to this question and the dilemmas it raises. But if the recommendation is meant to apply to controversial areas of science, some specific dilemmas arise.

An issue for “content-transcendent goals” for science education is that they take no account of the difficult nature of the knowledge base that gives meaning to scientific evidence (Norris 1997). Stephen Norris points out that scientists themselves have difficulty judging new knowledge claims outside their own areas of expertise. Others have suggested that this difficulty can be overcome when students learn to adopt a critical awareness of scientists’ likely motivations—that is, to take a more
sociological approach to judging contested knowledge claims (see, for example, Bingle & Gaskell 1994). However, Norris says this, too, is problematic because it “presupposes that the non-expert is, first, able to tell who are the experts and, second, that they are able to compare expert opinions for similarity of meaning” (Norris 1997, p. This returns us squarely to the content question. Besides, Norris argues, relying on authoritarian sources can be a rational response in many situations, and never to do so is to live with “pathological doubt” (Norris 1997, p.254).

Like Morris Shamos (1995) Norris is highly critical of the vagueness of many of the claims made in the name of “science literacy”. He applauds the moral agenda in the argument to move towards intellectual independence by creating a classroom climate that moves beyond an expectation of authoritarian teaching and rote student learning. However, his proposed approach is much more cautious, and mindful of the need for further research. He suggests that what is needed is to help students develop their dispositions to think more critically about the application of science knowledge in the world. Students would be encouraged to develop a habit of bringing appropriate levels of “epistemic distance” to situations, which Norris defines as “a cognitive distance between hearing a claim to scientific knowledge and believing that claim is warranted” (Norris 1997, p.253). To do so, he suggests that students should be helped to build all the following “metascience” resources (which I here interpret as developing NOS understandings):

- recognising the range of epistemic responses that can be appropriate in differing science situations (withholding judgement, doubting, believing cautiously, believing strongly, believing without doubt);
- developing a metalanguage for talking about the nature of scientific knowledge (causal claim, observation, justification, evidence, explanation, hypothesis, etc.);
- understanding the “justificatory shape” of science knowledge claims (what counts as justification, processes engaged in, etc.); and
- criteria for judging experts (role and weight of consensus, prestige, publication, successful competition for research grants, etc.).

Norris suggests that these understandings should be developed in the context of real-world problems that currently affect students’ lives.
“Inquiry” approaches

Inquiry is another term with a similar range of multiple meanings. At one end of a continuum it may simply mean that students carry out more or less traditional (albeit perhaps somewhat open-ended) science investigations. Such an interpretation is problematic when inquiry is represented as oversimplified, singular “scientific method” (Jenkins 1996) which tends to emphasise “fair testing” at the expense of more systems-related methods of inquiry (Mayer & Kumano 1999).

Even when fair testing is not seen as the only stereotype of scientific method, teachers may nevertheless conflate epistemological aspects of NOS with processes of scientific investigation (Abd-El-Khalick, Bell & Lederman 1998). Noel Gough (1998) notes that when teachers present “the scientific method” to their students they are following the practice of scientists themselves in stereotyping and mythologising the way science knowledge is produced. If this process/NOS conflation is as common as others have also suggested (for example, Hodson 1988), teachers may genuinely believe that students are learning about the nature of science as they carry out typical practical work activities (Hipkins & Booker 2002). Yet there are a number of ways in which school science and professional science differ profoundly (Chinn & Malhotra 2002).

If procedural knowledge of how science investigations are done is to be an explicit focus for developing NOS understandings, “concepts of evidence” seem to be a more fully realised target. Over a number of years these have been researched in a variety of real-life settings where scientific knowledge underpins actions taken, at least tacitly. These have included industrial workplaces (Duggan & Gott 2002), nursing in critical care wards (Aikenhead 2005), and school-work “vocational” placements (Chin et al. 2004). Some argue that learning about these is relatively more important than gaining conceptual knowledge, because the latter tends to be learned as and when needed in adult life (Duggan & Gott 2002).

Science-Technology-Society

Within an S-T-S framework, the NOS focus is more sociological and concerns people’s relationship to science, including understanding ways science impacts on our culture (Black 1993; Hurd 1997, 1998) and of its potential for negative as well as positive consequences (Roth & Desautels 2004). The focus might be, for example, on
exploring contemporary socio-scientific issues that impact on citizens’ lives (Levinson & Turner 2001; Sadler & Zeidler 2004; Zeidler et al. 2002). Sounding a note of caution about the contexts that should be used, Wolff-Michael Roth and Jacques Desautels (2004) warn that students should not be engaged in researching and discussing contexts and issues that are pressing for others, but not yet personally meaningful for them. An example might be discussing ethical dilemmas faced by parents of a child with a specific genetic condition. While students might well be interested in an academic way, there would likely be little they could personally do to address the relevant ethical issues, and so they would become voyeurs in the dilemmas of others.

With the above caveat, S-T-S approaches can allow students to investigate real problems of direct personal relevance to their lives (Lemke 2005; Roth & Desautels 2004). Both sociological and epistemological aspects of NOS are likely to be needed here. However the warning that the learning cannot ignore the content aspects of the situation is timely (Norris 1997). Students are likely to need considerable support where the science is difficult and carefully developed case studies may be needed to scaffold students’ learning (Tytler, Duggan & Gott 2001). Based on case studies of real socio-scientific issues, several research teams have raised the caveat that students will also need to draw on relevant everyday knowledge, and knowledge from other discipline areas if they are to critically interrogate the claims being made in the name of science (Roth & Desautels 2004; Tytler et al. 2001). As Norris (1997) points out “scientists have no special expertise in the moral, prudential, economic, aesthetic, or other grounds that bear upon the justification for an application of science” (p.255).

**Learning about professional science**

One approach to NOS advocates for students to learn more about the variety of ways actual scientists carry out their current work. Contemporary stories should emphasise the importance of multidisciplinary frameworks within strong social contexts (Tytler & Symington 2005). It is important that students with a talent for science realise that a variety of career options are open to them, not just the traditional fields of medicine, veterinary, and dentistry (Hipkins et al. 2006). Thus this type of learning could potentially meet certain specific learning needs of future scientists, as well as
helping all students prepare to participate as future citizens in a world impacted by ongoing scientific activities.

This interpretation of NOS is directly aligned to the aims of the teacher fellowship. As Sections 5 and 6 will show, teachers do indeed gain rich contextual knowledge of the science carried out in the setting(s) in which they work and they value the rich personal stories they gain to take back to their school context. However, if NOS is framed from a more theoretical epistemological or sociological perspective, then the sorts of insights that lead to teacher learning about these perspectives will arguably be more dependent on the NOS knowledge (if any) of the scientists with whom the teacher works during the fellowship. Accordingly, in the third interview I asked whether any NOS conversations had taken place at work during the fellowship year.

**Summing up the arguments**

Notwithstanding the extensive research literature, for which I have provided only an indicative sample, the outcomes that could be achieved by the inclusion of NOS in the curriculum remain contentious. It is not difficult to see that ideas about what science actually is (that is, NOS ideas) are potentially threaded through all the above recommendations, yet may be interpreted quite differently, depending on the emphasis adopted. The above suggestions seem to me to form a continuum of notions of NOS meta-analysis—one that is linked to an increasing focus on actual contexts and meaningful investigations of real questions or problems, not just contrived school science activities. The next figure summarises the trend.

![Figure 1 NOS in the curriculum: a continuum of possibilities](image)

At the right hand end of the continuum NOS includes a mix of epistemological, sociological and contextual knowledge. Gaining this mix seems a very challenging ask, even for a teacher with a year out from the demands of the classroom.
The translation of NOS into the school curriculum

To date, the approach taken to translating NOS ideas into the school curriculum has been largely epistemological. Since the pioneering work of James Rutherford and Andrew Ahigren (1990) there have been numerous attempts to articulate knowledge propositions about science suitable for a range of school-age students. Some researchers have sought consensus about such propositions amongst experienced science educators (for example, Millar & Osborne 1998; Ratcliffe et al. 2001). Others have worked backwards from real-life situations that required decision making about specific socio-scientific issues (for example, Ryder 2001). Some researchers assert that there is now an acceptable level of generality regarding NOS ideas that are accessible to school students (Abd-El-Khalick & Lederman 2000a). Even given this level of consensus about NOS propositions, how to actually develop NOS understandings is another matter entirely.

Teaching to develop epistemological NOS understandings

Advocates of an epistemologically-focussed NOS may recommend learning experiences that build relationships between theory and evidence (Solomon, Scott & Duveen 1996). Some argue that the development of “concepts of evidence”, with an associated understanding of the twin concepts of reliability and validity, should be valued as an outcome of science education in its own right (Duggan & Gott 2002; Gott & Duggan 1998).

Learning the skills of “argumentation” has been advocated as one way of providing students with opportunities to critically examine relationships between ideas and evidence (Driver, Newton & Osborne 2000; Munby & Roberts 1998; Osborne, J. et al. 2001):

Argument refers to the substance of claims, data, warrants, and backings that contribute to the content of an argument; whereas argumentation refers to the process of assembling the components (in other words, of arguing). (Simon, Erduran & Osborne 2006, p.237)

A recent investigation of professional development to help teachers develop the skills to teach “argumentation” found that teachers can and will change their pedagogy given the necessary support, including opportunities to learn together, and materials that can be adapted for their classroom practice (Simon et al. 2006). However, critics
of this research have noted that Shirley Simon’s team counted the argumentation strategies but did not comment on the quality of the arguments made (Yore & Treagust 2006). Such critique resonates with Norris’s warning about content-transcendent goals for intellectual independence (Norris 1997). The challenge is to keep clear knowledge outcomes in mind, while still providing opportunities to develop NOS outcomes. A related challenge is that evidence and arguments concerning real-world issues are likely to draw on more than one curriculum area, and on everyday knowledge, not just scientific evidence (Roth & Desautels 2004; Tytler et al. 2001).

Simon and her colleagues (2006) reported that each of the 12 teachers in their study had a unique pedagogy to begin with. Their understanding and uptake of the professional development was influenced by their initial understanding of argumentation, which led the researchers to assert that “teacher’s basic capacity for change may be dependent on their existing knowledge and understanding” (p.256). Interestingly, early in the two-year professional development programme, the teachers were anxious that presenting alternative theories to their students would cause confusion and perhaps reinforce unscientific ideas. In Section 5 I report similar concerns held by my thesis participants. If teachers see it as their responsibility to ensure traditional “content” is correctly learnt, they are likely to take on most of the intellectual work being done, and to arbitrate away uncertainties that arise. It seems that bringing together teaching for knowledge and teaching for NOS demands a lot of teachers and they may not be used to thinking in sustained ways at this sort of level. As Eleanor Duckworth vividly described some years ago, keeping teachers’ science learning “complex” requires a commitment to a sometimes lengthy cognitive engagement and intellectual struggle (Duckworth 1991).

Others who have been active in developing epistemologically-focused NOS materials have reported another dimension to teacher anxiety. When provided with carefully structured materials to draw out students’ NOS ideas, Andy Hind, John Leach, and Jim Ryder (2001) found that some UK teachers were reluctant to identify any such ideas as incorrect. Wanting to handle the proffered ideas sensitively led some teachers to respond ambiguously to naïve NOS views of their students. However those teachers who were more confident of their own NOS understandings did cope better with peer and whole-class debate and gave clearer feedback about students’
ideas. This finding was reiterated in the most recent work of this team (Ryder & Leach 2005).

**Teaching to develop sociological NOS understandings**

It seems to me that, to date, less research attention has been paid to ways of actually developing sociological NOS understandings, beyond active participation in an actual science inquiry in an institutional setting, as outlined above. Teaching for sociological NOS insights aligns with sociocultural teaching and learning approaches such as CHAT (cultural historical activity theory) (Wells & Claxton 2002). Yet most teachers’ views of learning are likely to be more closely aligned with information transmission, or perhaps with cognitive approaches such as constructivism that have so dominated the vast area of science education research on students’ misconceptions (see, for example, the extensive listings of Pfundt & Duit 2000).

One exception is narrative pedagogy, which has been advocated as a means of helping students develop various dimensions of sociological NOS understandings. These can be historic, focusing on the contextual and epistemological complexities involved in building now settled science theories (Irwin 2000; Solomon 2002). However it is important that history of science stories are not presented as “history by hindsight” because such an approach can promote a “whiggish” view (Barker 1999) of the inherent superiority of current theories and thinking (see also Allchin 2004). Narrative materials could alternatively be focused on the current work of today’s scientists (Tytler & Symington 2005) or on rich case studies of actual socio-scientific disputes (Tytler et al. 2001). A third type of narrative approach is to use science fiction to help students think critically about the relevance of science to their lives, and to think more creatively about where it may take us in the future (Gough 1993, 2004a; Weaver, Anijar & Daspit 2004). Yet another approach is to use narrative to help students make “border-crossings” (Aikenhead 1996) between their own cultures and worldviews and those of science (Bruner 1986; Gilbert 2001).

Notwithstanding the wide scope of these possibilities, the use of narrative pedagogy has a number of challenges. There is a need for curriculum materials developers to experiment to find what works (Solomon 2002) and some potential pitfalls have been discussed. For example, narrative learning materials draw on “everyday” means of communication that are very different from the “logico-scientific” mode of
communication (Bruner 1986). Understanding how such communication is different from everyday narrative communication can be seen as an important aspect of “science literacy” (see, for example, Wellington & Osborne 2001). Yet my personal experience of preparing narrative resources for use in bicultural contexts suggests they can easily become a type of “faction” (facts conveyed in a fiction-like style of text) that uses neither the accepted genre conventions of science communication nor, actually, those of narrative (Gilbert, Hipkins & Cooper 2005). This seems to me to be an area in need of more research, but also one in which teachers need ideas and approaches that are easier to use and to resource.

The uncertainties attending the few types of explicit teaching strategies that have actually been developed thus far seem to me to compound issues associated with teachers’ seeming reluctance to include explicit NOS goals in their teaching. This is a challenge I turn to next and will return to several times as the thesis unfolds.

**The non-uptake of NOS aspects by science teachers**

A science education that could help achieve the sorts of NOS understandings sketched above clearly demands very different knowledge and skills of teachers than traditional “content delivery” could allow. Are these impossible ideals? The question is critical because it seems that, on the whole, school science teachers remain untroubled by the “science wars” of the philosophers, or the well-intentioned deliberations of the curriculum policy makers. Science teachers typically ignore NOS learning goals (Abd-El-Khalick & Lederman 2000a).

Why do teachers let the more theoretical philosophical and sociological NOS discussions go over their heads? Why do they persist with teaching the familiar, while ignoring critique about both purposes and methods of their work? Pondering these questions, I have been very conscious that I did the same when I was a classroom teacher. I remember how threatening some NOS ideas felt when I first encountered them. What’s more, most of the people I know who have an interest in NOS and associated theoretical concerns are not schoolteachers, even if like me, they once were. Again, several themes can be discerned in the extensive literature that discusses “the problem” of teachers’ seeming unwillingness to change their practice.
NOS knowledge deficits

The science education literature often suggests that what is needed is a better education in NOS ideas—that teachers don’t teach to develop these understandings with their students because they were not part of their own experience of science education. This deficit argument suggests that, lacking experiences of actual scientific research themselves, the tacit realist/empiricist views likely to have been gained during their own education simply go unchallenged (Gallagher 1991; Thoermer & Sodian 2002). But Norman Lederman and Dana Zeidler (1987) point out that causal relationships between teachers’ and students’ NOS views, and between teachers’ espoused NOS views and their teaching practice are usually assumed. Lederman (1999) further notes that holding more contemporary espoused NOS views is no guarantee that teachers will make these part of their instructional goals, which are more likely to focus on managing the class or promoting science. The latter allows teachers to share in something of the prestige of science, albeit from the very fringes of its institutional activity. Section 6 suggests membership of the science community can be a powerful, if conflicted, lure for science teachers.

An analysis of research reporting on NOS professional development initiatives suggests that such learning experiences hold no guarantees that teachers will change their well-established naïve realist NOS views. This is especially likely to be so if the initiative incorporates NOS views implicitly, is short lived, and does not provide opportunities for reflection on current NOS understandings, as these relate to teachers’ classroom practice (Abd-El-Khalick & Lederman 2000a). More encouragingly, multiple learning experiences might interact positively. For example, one project has shown that teachers who had already learnt some NOS gained more NOS insights from history of science (HOS) courses than teachers whose views were naïve at the outset (Abd-El-Khalick & Lederman 2000b). And, as outlined above, professional development initiatives that focus on pedagogy to develop one explicit NOS focus, such as argumentation, have met with modest success, albeit with hints that some teachers are hindered by deficits in their professional knowledge (Simon et al. 2006).

Following Lee Shulman’s (1987) notion of pedagogical content knowledge (PCK) some science educators have pointed out that teachers need to have what they have called “NOS PCK” (Abd-El-Khalick & Lederman 2000a, 2000b). Research reported
above (Ryder & Leach 2005; Simon et al. 2006) shows that, with support, teachers can gain varying degrees of PCK that could help them shape epistemological NOS learning experiences for their students. However, one of these projects also emphasised the “uniqueness of pedagogy” for each teacher (Simon et al. 2006, p.256). PCK encompasses teachers’ views of learning, and of the purposes for science learning, as well as their willingness to expose students to a level of risk and uncertainty. Knowing about NOS itself, and about teaching strategies to develop it, is just one aspect of the PCK implicated in this complex issue.

Lack of NOS PCK has also been identified as an aspect of teachers’ reluctance to change their teaching practice to include discussion of socio-scientific issues. They struggle with the pedagogical implications of including matters of values and opinions, when their primary focus has always been on scientific “facts” (Dawson et al. 2002; Levinson & Turner 2001). Recognising the multidisciplinary nature of questions that arise from socio-scientific issues, and acknowledging that these may be addressed in different ways when framed from differing perspectives (Stanley & Brickhouse 2001) requires that teachers hold contemporary NOS views. If teachers do encourage such discussions, scientific knowledge is likely to be represented and/or received in naïvely relativist ways when teachers do not hold the necessary NOS PCK to be able to make sophisticated worldview comparisons (Elby & Hammer 2001).

**Misinterpretation of NOS themes**

Teachers’ NOS views have been formed over a lifetime of experiences. Their distal NOS views (what they say they think NOS is) may well be distinct from their proximal NOS views (what they do to represent NOS in the classroom) (Hogan 2000). During their own education, teachers’ experiences of “doing” science will have powerfully shaped their proximal NOS views, albeit implicitly. Since such experiences typically do not include authentic scientific research (Gallagher 1991; Nott 1997; Thoermer & Sodian 2002) these proximal views, which remain substantially unexamined, are highly likely to misrepresent the true complexity of professional science. Douglas Roberts and Leif Ostman (1998) suggest that teachers are highly likely to convey “companion meanings” about a realist NOS, via the manner in which they interpret and represent conceptual knowledge of science as the way the world is, via the largely transmissive teaching methods they habitually use.
Ironically, the Science-Technology-Society (S-T-S) framework that shaped late twentieth century attempts to introduce learning about science into the curriculum (for a review, see Cross 2003) may have unintentionally created a distracting side-debate about the relevance of technology to science learning. In New Zealand, technology is a distinct curriculum area. But there is also a “technology” component in the NOS strand of the current New Zealand science curriculum. Teachers have long used “applications” to demonstrate to their students the power of science in the real world and some New Zealand teachers have taken this practice to mean they are teaching science “in context” (Hipkins & Arcus 1997). While a more critical S-T-S focus could be read into the NOS strand of the science curriculum, it is perhaps more familiarly seen as an uncritical “applications” promotion of importance of science for contemporary life. It does seem that some teachers believe that they are addressing NOS by including references to technological applications of science, or they may see this strand as having become irrelevant once the technology curriculum had been developed (McGee et al. 2003). Something of this dilemma can be seen in the teachers’ comments reported in Section 5.

Lack of interest in NOS

It may be assumed that some teachers are not interested in NOS debates, and do nothing to further develop their personal NOS understandings during their teaching careers. This, too, may be an over-generalised response. Are teachers really so very naïve in their understandings of the complexities of working science? In my experience many secondary science teachers are avid readers of science stories produced for the lay public where epistemological (Bodanis 2000; Edmonds & Eidenow 2001; Wertheim 1999) and sociological (Sobel 1995; Wertheim 1997) complexities are thoroughly explored. Some teachers with whom I have direct personal contact have read the books cited and they represent just a small selection from the available literature. Similarly the many multimedia presentations readily available on television “discovery channels” are often infused with NOS themes. One of my participants, Sarah, provided evidence of such an interest when, at the beginning of the second interview, even before I had asked the first question, she told me a rich NOS story. This exchange, detailed in Section 5, was ultimately pivotal to the development of the methodology I used to analyse my data, as outlined in Section
4. When an avid personal interest does not translate to the classroom, it seems likely that more pressing agendas are at work.

More pressing agendas
The NOS views to which teachers seem to subscribe in the context of their teaching practice need to be viewed in the light of educational traditions and day-to-day classroom realities. For example, secondary teachers must prepare students for high-stakes examinations, and so will teach what they perceive students need to know to gain qualifications. Two other research projects I have recently led certainly show this to be a significant influence on teachers’ decision making (Hipkins, Conner & Neill 2006; Hipkins et al. 2004). The tendency for formal assessment to drive curriculum decision making is a potentially strong countering force to any NOS innovation as long as such assessments focus largely on uncontested “content”. Since such a focus is hegemonic, with its ideological dimensions deeply buried (Apple 2004), it is a brave teacher indeed who chooses not to capitulate to the “content” agenda. Of course many do not. Making this excuse for not considering change may be a surface response to some much deeper NOS issues that I explore as the thesis unfolds, beginning with views of “reality” in Section 3. I also return to the issue of stated teaching priorities in Section 6.

Ontological realities of schooling
Research from several different fields supports the assertion that the experience of schooling is implicated in the production of teachers’ seemingly empiricist/realist NOS views. From a sociocultural perspective, Martin Packer and Jessie Goicoechea (2000) assert that schooling actively produces students as people who learn to hold the world separate from themselves and hold it out for objective inspection. In a similar vein, when discussing teachers’ tendency to “thingify” science knowledge, Jacques Desautels and Maria Larochelle (1998) ponder:

. . . what if the experience of schooling had something to do with the tendency of students to picture as the lessons of things and tangible effects what otherwise in scientific knowledge remains tentative? (Desautels & Larochelle 1998, p.115, emphasis in the original)

Jon Ogborn, Gunther Kress, Isabel Martins and Kieran McGillicuddy (1996) note the challenges that face teachers as they talk an “ontological zoo” of entities into being
in their classrooms. It may be that such empiricist/realist NOS ideas develop “by accident” (Munby & Roberts 1998) as a product of the challenges of communicating during teaching. Perhaps reflecting the ongoing impact of these influences, Vassilis Koulaidis and Jon Ogborn (1989) found that science teachers in their survey held more inductivist views of scientific method than did student teachers. Deborah Pomeroy (1993) found more positivist views amongst scientists and secondary teachers than among primary teachers (who teach very little science).

Other aspects that impact on teachers’ classroom decision making are known to include factors such as views of self as a learner in science (Eick & Reed 2002) and teacher role identity (Helms 1998). These are further explored in Sections 5 and 6.

Rethinking deficit views of teachers’ NOS knowledge

A book of case studies of teacher change (Wallace & Louden 2000) illustrates the risks taken by teachers who expose their thoughts about their teaching practice to the critical scrutiny of researchers. Three or four commentaries are provided on each case—which is typically written in the first person voice of the teacher. In the very first chapter I read the nominated “experts” were critical of a teacher’s candidly outlined doubts in a chapter about the ethical dilemmas that can arise when teaching about the issue of organ transplantation. My unease grew as I read a chapter called Science for All where another teacher described a situation that I think most teachers would dread—the really difficult class, taught last thing on a Friday afternoon, in a too-small teaching space. The title of one critique says it all: “Surviving science lessons is not science for all.” Because she did not choose content of immediate applicability to her students’ lives, said the critique, this teacher was not addressing their needs as learners and so could not say this was a case of “science for all”. The sense of joy in her own learning, so evident in the teacher’s words, would surely have been snuffed out by this type of negative commentary. I tried a third case—Culture and Ethnicity—and here the harsh commentary was ameliorated only by the fact that the case was an invented one.

The view of teachers taken by these researchers is very much a deficit model. Steve Miller (2000) defines this as a model that uses a “one-way, top-down communication process” (p.3) where knowledge flows from the “pure” theoretical source to the more
applied/everyday situation. In the case of NOS, the science educators and researchers are keen that their knowledge flows down to teachers, and yet teachers are often criticised for taking a deficit view of students, when they transmissively teach science “content” in a similar manner.

of course it is easier to sit in judgement in any situation than to do something constructive to address the challenges raised. And the challenges seem to me to be considerable if a focus on epistemological deficits is to be transcended but not avoided. Speaking about recent developments in the field of public understanding of science (PUS), Miller further notes that:

The end of the deficit model does not mean there is no knowledge deficit. Government and industry pay out large sums of money to scientific researchers. If there is not a gap between what members of the general public know and what scientists know about science, then something is very wrong. We do not want a public understanding of science political correctness in which the very idea that scientists are more knowledgeable than ordinary citizens is taboo. Scientists and lay people are not on the same footing where scientific information is concerned, and knowledge, hard won by hours of research, and tried and tested over the years and decades, deserves respect. (Miller 2000, p.4)

This comment is useful for two reasons. As already stated, it draws attention to the considerable challenges of addressing knowledge deficits constructively. However it also begs a question about where the expertise of professional scientists lies. They have “hard won knowledge” of science concepts and theories, and contextual knowledge of how these ideas were generated, at least in their own field. But this is not the same as knowing about the epistemology and sociology of science at a more general level of abstraction. Indeed I have already noted that many scientists contest these ideas. Being in the thick of producing science is not a guarantee of insights into meta-level discussion of the nature of its production! Some distancing would seem to make this easier to do. Scientists, no less than teachers, are immersed in contexts which help shape their personal ontologies in particular ways. Perhaps this is why NOS research is usually the preserve of science educators and social scientists.

Thus the research evidence presented in this section suggests that science educators do need to support teachers to develop better NOS and NOS PCK understandings, in all their complexities, if the latter are to widen their teaching agendas to include these aspects. There may be a deficit, but the challenge is to address this while avoid alienating teachers with a top-down approach that takes no account of the realities of
their teaching contexts, or that fails to make meaningful connections to their current understandings and interests, both of science and of science teaching. This section also suggests that exposure to working science is unlikely, in and of itself, to be sufficient to help fill the deficit. Once this was clearer to me, I rethought my interactions with the teachers. Instead of seeking direct evidence of NOS learning (or not) I used the interviews to try and better understand the realities of their work, hoping to shed a different kind of light on the non-uptake of NOS in science teaching.

In the rest of this thesis I attempt to meet the considerable challenges outlined above by undertaking a radical rethinking of NOS as a school science curriculum focus. I believe that the epistemologically-focused reform efforts to date have been too academic and remote from teachers’ personal interests, professional challenges, and sense of ethical responsibility for their students’ welfare and future learning progress. Would-be reformers could rightly be indignant at the latter proviso, saying that they also intend that students are better prepared for their future lives. The challenge, as I see it, is to bring the intentions and the reality closer together so change can actually be achieved. To that end, I explore the potential of paying much closer attention to ontology, not just epistemology, as a means of bringing the NOS focus into a twenty-first century science curriculum. My focus is on doing so in a manner that will make more immediate sense to teachers, whilst also drawing them into an ongoing and compelling learning journey of their own.
3. “Reality” and science teaching: the turn to a different ontology

Introduction
This section lays the groundwork for building on the “ontological turn” my project took in midstream. I begin with my understanding of the traditional meaning of ontology in philosophy. I then briefly document three differing traditional ontological accounts of “reality”. My intention is to subsequently position all three as problematic in the light of ideas from science studies. I do this by introducing different ideas about reality from ICT, science studies, and complexity science perspectives. They have in common ontologies that are non-dualist, multiple, and emergent. These new directions have implications for the continuous rethinking of my own research, as discussed in Section 4.

Finally in this section I outline traditionally framed ideas of epistemological development in order to explore the challenges that relativism raises in relation to ways science teachers can safely portray traditional views of NOS in their work. I argue that any NOS approach must take account of these difficulties, if it is to be more widely adopted into teachers’ work. I suggest that the non-dualistic ontologies outlined have the potential to meet this challenge.

The traditional meaning of ontology
Teachers often ask me what “ontology” means. Ironically, I find it easiest to begin my explanation by posing a binary—if “knowing” is the study of epistemology, then “being” or alternatively, “reality”, is the study of ontology. The Wikipedia—an interactive online encyclopaedia—uses both terms in its definition of ontology, or at least did so on the day that I last visited this definition:³

In philosophy, ontology (from the Greek ὑντος: being (part. of ἔινα: to be) and λόγος: writing about, study of) is the most fundamental branch of metaphysics. It

³ As we shall shortly see, my choice of this source of “authority” was deliberate, and intended to raise issues.
studies being or existence as well as the basic categories thereof—trying to find out what entities and what types of entities exist. Ontology has strong implications for the conceptions of (Wikipedia 2005)

The Wikipedia goes on to say that ontology “must give an account of which words refer to entities, which do not, why, and what categories result” (Wikipedia 2005). An issue for my thesis is how the word “entity” in this definition is interpreted. As a rough working guide, I am going to use “reality” to refer to ontological questions about the natural/physical world and “being” to refer to ontologies of the social/experiential world—causality, power, order, and so on. While my main focus is on ontology as the study of reality, in keeping with the NOS questions I want to explore, I cannot avoid the social questions that are inescapably bound up in both science and teaching. In another ontological irony, I have planned an initial way forward by using a second binary (nature/society) to temporarily manage the complexities of the ontological terrain.

From a NOS perspective, Bruno Latour (1999) hints at problems with the “common sense” of the knowing/reality binary:

Philosophers of science like to remind us, as if this were the epitome of good common sense, that we should never confuse epistemological questions (what our representation of the world is) with ontological questions (what the world is really like). (Latour 1999, p.93)

He goes on to say “confusing those two supposed separate domains is precisely what scientists spend much of their time doing” (p.93). In order to understand his argument, it is first necessary to keep the binary in place, and to briefly explore the consequences. Binary thinking traces back to Greek theories of knowledge (Latour 1991 ; Latour 1999; Biesta & Burbules 2003). It is a pervasive but nearly invisible categorisation system that does ontological work by its naming and framing of various entities in both the physical and social world. For example, as feminist researchers have often pointed out, placing concepts such as male and female in a binary opposition “allows no movement and inevitably privileges one over the other” (St. Pierre 2000, p.478). There is a “reality” component here, related to characteristics of physical bodies, but also a “being” component, related to our experiences of that gender identity.
The mind/world binary that solidified with the development of Enlightenment science privileges the mind and, in philosophy and science, continues the Greek tradition of rendering problematic knowledge constructed from direct experience of the world (Biesta & Burbules 2003). Bruno Latour says this has created ongoing problems for being able to say with confidence what is really real, because a “brain in a vat” has no immediate check against experience, resulting in increasingly tortuous justifications of ways of constructing “truth” (Latour 1999). He uses the metaphor of an incorrect turn in the philosophical path, increasingly entangled in brambles, to explore the consequences of the mind/world dualism. These consequences, in the form of competing views of reality, are briefly outlined next.

**Ontology and differing accounts of reality**

Clay Shirky (2005) thinks of ontology as essence, or “is-ness”. He asks “In a particular domain, what kinds of things can we say exist in that domain, and how can we say those things relate to each other?” (p.1). Philosophers answer this question differently, depending on their views of how the “real” can be justified. For the purposes of my thesis I restrict the following summary to several very broad schools of thought. Within each there are contested variations and philosophers would doubtless object to the inadequacy of my grouping. However my purpose is to explore why such debates have seemingly found no place in formal science education and so my division mainly takes its cue from a typology presented in the context of educational debate. In a discussion of various forms of constructivism and their implications for education, Larry Yore (2001) identifies three broad ontological positions. He calls them realist, naïve realist, and idealist respectively. For the purposes of the argument I am building here, these three broad ontological positions, likely to hold at least some familiarity to educationalists, are sufficient to signal that rather different philosophical positions are available, even within a traditional ontology. However I do not think the names Yore has chosen are especially informative, for reasons I will shortly outline, and I have modified them. The three positions I next outline are scientific realism, critical realism and finally idealism.
Empirical or scientific realism

The various versions of scientific realism take the ontological stance that a real world exists and is ultimately objectively knowable through the inquiry methods of science. What Yore labels a realist ontology is associated with a traditional “absolutist” epistemology (Yore, Hand & Florence 2004), a mechanistic worldview that assumes nature is the ultimate judge of reality, and a view of teaching as a one-way flow of information from teacher to student (Yore 2001). Its underpinning assumptions are structured by metaphors drawn from the linear thinking of Euclidean geometry and there is an “unquestioned assumption that reality has a developmental structure” (Davis & Sumara 2005, p.307). Brent Davis and Dennis Sumara also identify a third type of assumption, that of reduction: “Phenomena, it is presupposed, can be broken down into simpler elements—ultimately, like the objects of Euclidean geometry, into fundamental parts, particles and laws” (p.307).

The mind/world binary that underpins this view of reality arose during the early stages of the development of modern science. From its inception it maintained Greek assumptions about the superiority of rational thinking over direct experience of the world, at the same time as it was built on empirical inquiry, which requires the interpretation of direct experience. Naïve inductivism was the strategy used to link these seemingly incompatible positions, with positivism and falsificationism as two associated epistemological developments (Chalmers 1982). Elaboration of the knowledge generated requires a “logico-scientific” or “paradigmatic” mode of thinking that most people find difficult to learn because everyday thought is carried out in the “narrative” mode (Bruner 1986). Whereas the logico-scientific mode of thought abstracts itself from everyday life, the narrative mode foregrounds people along with their actions, motivations, and relationships. Thus, when ideas are communicated in language from within the logico-scientific mode, experience is set aside and logic dominates the discourse.

In recent years this type of realist ontology has been strongly critiqued by philosophers of science. There have been calls for a rethinking of its ontological positioning of the reality of the world as the ultimate “truth” by some who wish to see a return to more “modest” forms of realism (Harre 1986). Critiquing its transfer from science to social science research, Sue Clegg (2005) calls this a “flat” ontology: “an ontology of an atomised, regular universe of facts in which regularity is taken as
(Humean) evidence of cause and effect, and where the real is reducible to experience” (p.420). While she uses different metaphors from Davis and Sumara, the critique is clearly of the same nature in science and in social science.

**Critical realism**

The second view of reality addresses objections to empiricism by recognising “the limitations of people and procedures in attaining an accurate interpretation of the real world and that stresses evaluation of all knowledge claims” (Yore 2001, p.4). In the sciences, rather than following one “scientific method” as in empirical realism, the type of inquiry will depend on the circumstances. However, knowledge claims are expected to change over time to “more closely reveal accurate insights about reality” (Yore et al. 2004, p.342).

In this view “truth” is conceived as making fallible statements about a world that is, nevertheless, really real. Hypothetico-deductive reasoning is added to falsification as an inquiry method (Yore et al. 2004). Yore calls this “naïve realism”, using naïve in the same philosophical sense as Latour (1999) to mean that the world and the language we use to describe it are put back into an interpretive, but not infallible, relationship with each other. I think this is an unhelpful name because naïve, in its everyday sense, is often associated with empirical realist views (see, for example, Lederman et al. 2002).

Critical realism is a social science response to the weaknesses of empirical realism and this is the term I prefer to use. For the critical realist “the fundamental first principle is that reality is knowable” (Cobem 1990, p.5) but social interactions must also be taken into account. Roy Bhaskar (1978) introduced the idea that there are three domains for ontology to consider—the real, the actual, and the empirical. Whereas the “real” is what exists “out there” in some transcendent form, the “actual” is what we experience as we live in and act on the world—i.e. there is a focus on “being” that is distinct from “reality”. The new idea of an “actual” domain allowed for identification of the impact of human events and behaviours on ways we experience the world, as measured and described in empirical terms. The addition of the actual domain led to the development of the idea of a “depth ontology” for the social sciences where causal mechanisms and power structures, explained via rich
descriptions of contextual features, count as important types of research evidence (Clegg 2005).

**Idealism**

An idealist ontology (or nominalist sociology) sits at the opposite end of a philosophical continuum to empirical realism. Idealism aligns with various postmodern worldviews where social interactions are the arbiters of “truth” in the world (Yore 2001)—that is, it links to ideas of intersubjectivity (for a concise discussion of this term see Davis 2004). Yore also aligns idealist ontology with both social and radical constructivism. William Cobern (1990) described the latter as “an epistemological philosophy that divorces knowing from any notion that reality is a referent of knowledge (p.3, emphasis in the original). Names, concepts, and labels are the epistemological devices used to structure what is ontologically “real”.

In the social sciences, there is a rich history of ontological debate about “being” and intersubjectivity that does not seem to be matched with equivalent debates about “reality” in the sciences. Indeed, as Davis and Sumara (2005) point out, the idea of intersubjectivity has “never really taken hold within the sciences the way it has within the arts and the humanities” (p.314). They suggest this situation relates to differences in the types of phenomena studied:

> Whereas the nature or meaningfulness of a piece of sculpture, a novel, or even language might be seen to rely on weaves of social signification, it is not clear that the same [ be said of falling objects, atomic structures and the biosphere. (Davis & Sumara 2005, p.314)

Some postmodern philosophers in the social sciences propose a “negative ontology” for which the “empty signifier” is a central idea. Empty signifiers are abstract, “pure” forms of “being” that sit at key nodal points where all the different potential and actual versions of that idea could meet, at least in theory. For example, the idea of struggle against repression in its “purest” form would encompass each and every situation in which such struggles, with their contextual particularities, take place. But since it is impossible ever to reach the limits of all such instances, the signifier must remain “empty” to accommodate the tension between differentiation and generalisation, and to signal the “lack” in each specificity (Laclau 1994).
These are very difficult ideas. Latour, for example, sees such idealist positions as a blind ending in a philosophical path that cannot lead constructively forward to solving the dilemma of how we can know what is really real (Latour 1999). He points out that the mind/world binary remains in place in all ontological positions on the realist-idealist continuum. He asserts that “our philosophical tradition has been mistaken in wanting to make phenomena at the meeting point between things-in-themselves and categories of human understanding” (p.71). He also sees it as ironic that social scientists have struggled with the implications of this binary for views of reality, while the natural sciences have largely ignored the ongoing dilemma. The second half of this section introduces his ideas about how this dilemma can be solved.

**The three ontological positions in science education**

Science teachers, like many scientists, tend to adopt a realist ontology to match their empiricist, positivist epistemologies, as outlined in Section 2. Jane Gilbert (2005) asserts that the accompanying common sense metaphors of “knowledge-as-object, mind-as-container” (p.74) are making it very difficult to help educators adjust to changes to the meaning of knowledge in the so-called knowledge age. This change is further explored shortly.

Derek Hodson (1998) describes how NOS messages in science education differ between critical realism and an empiricist (realist) ontology with its associated inductivist epistemology:

In the old stereotyped school curriculum view of science, scientific knowledge exists ‘out there’ and scientists carefully, systematically and exhaustively collect information that reveals it. In this revised view, scientific knowledge is created in the minds of people and then scientists go out and look for evidence for and against the ideas they have generated. (Hodson 1998, p.208)

The link to an epistemological NOS, as outlined in Section 2, is evident in this statement. However NOS need not only be a curriculum question. Raising an issue of pedagogy, Yore (2001) links critical realism with interactive epistemologies, where learning is still seen as primarily an individual activity, but which is “verified by the
epistemic traditions of a community of learners” (p.4). He sees this as a comfortable fit with certain non-radical forms of constructivist teaching.

Bo Dahlin (2004) makes a link between idealism, reductionist science, and the challenges of teaching science. He says that an idealist ontology reduces “our experience of the world to abstract representation and mathematical formulas in which the concreteness and contingencies of everyday life are annihilated, as it were—or at least set aside as belonging to the ‘not real’” (p.1). For him this creates the challenge of “ontological reversal” when some (but not all) of these abstract models become “more real than the concrete, lived experience in which they have their ultimate ground” (p. Molecules, elementary particles, and genes are examples he cites.

Ogborn et al. (1996) describe the abstracted entities of science as “tools for thought, even if to start with they are only things to think about. They have to become entities which are part of explanations, not things which are explained” (p.14, emphasis added). There is a real dilemma here for science teachers. These entities have to become “thingified” (Desautels & Larochelle 1998) if students are to demonstrate their understandings of them in explanations, but the ontological reversal this entails reinforces the distancing of science from the human life-world (Dahlin 2004). What are the consequences for views of NOS if students have no appreciation of the empirical experiences that led to these entities of science being built in the first place? At the very least, “naïve” NOS views that lead students to think, for example, that scientists can see atoms with high-powered microscopes (Hipkins 1998; Lederman et al. 2002) may be one such consequence. Here, then, is an important NOS tension that arises from communication in the logico-scientific mode, where the rich stories of knowledge construction have been “washed away” (Bruner 1986).

New ideas about ontology, reality, and knowledge

The three broad ontological positions—empirical realism, critical realism, and idealism—all entail an ontology in which mind and world are held in binary separation, issues of how we “really know” can never be escaped (Latour 1999). Newer non-dualistic ideas about ontology seek to avoid this philosophical trap, in ways that are outlined next.
ICT, open ontologies, and complex systems

Shirky (2005) discusses ways in which the meaning of ontology has changed as online environments have evolved. On the one hand, the meaning of ontology in online communities may narrow to mean the structures and links within and between websites, akin to traditional library filing systems. Here the categories are decided in advance, and the user must anticipate the classification scheme to be able to use to find specific items. However, online environments have also sparked the development of “open ontologies” that Shirky describes as more “organic” ways of organising knowledge. The Wikipedia provides an interesting example.

I turned to the online encyclopaedia—the Wikipedia—for my beginning definition of ontology because this internet development seemingly undermines traditional sources of ontological authority. Built into the Wikipedia is the capacity for continuous interactive rebuilding of categories of knowledge by anyone who has something new to contribute to the ways any category is named and shaped. Editors keep a watching brief but the perpetuation of an authoritative account of reality is ultimately a democratic exercise. A similar profound shift in ways people can participate in the naming and categorising of the world is heralded by the huge popularity of Google. This search engine differs from its forerunners in that it “can decide what goes with what after hearing from the user, rather than trying to predict in advance what it is you need to know” (Shirky 2005, p.8, emphasis in original). In these online contexts participation and interactivity drive ontological categorisation in a constantly evolving manner. Nicholas Burbules (2000) notes that such changes “are happening very rapidly, and in a self accelerating way: they build upon themselves, exponentially” (p.40).

Open ontologies in online environments illustrate how new properties can “emerge” in complex systems. As Davis and Sumara (2005) comment, “a complex system is not just a form with more parts, but one that transforms itself as it experiences its world. Complex systems adapt and learn” (p.3 12). Note that these words make no distinction between human and non-human components of a system, nor do they assume parts of the system can act independently of one another. There is no trace of either mind/world or nature/social dualities. To underscore that this is a very different type of ontology, they go on to say that complexity theories refute determinism, demote analytic reduction as an inquiry method, and reject metaphors
related to Euclidean geometry as tools for interpreting phenomena. For them, fractal geometry is a more appropriate metaphor for the complexity of the phenomenal world.

These ideas spring from a recent and profound shift to systems thinking within some branches of the sciences (Davis & Sumara 2005; Gribben 2005) and signal real challenges to the more traditional epistemological NOS focus in science education. To illustrate, at the more conventional end of curriculum debate there have been calls for a more systems-focused approach to science teaching (see, for example, Mayer & Kumano 1999). Gough (2004a) goes much further, suggesting that current science education, focused as it is around laboratory science, misrepresents the current state of the field:

> But in the study of complex systems—protein folding in cell nuclei, task switching in ant colonies, the nonlinear dynamics of the earth’s atmosphere, and far-from-equilibrium chemical reactions—the emphasis is on modeling their informational structure through computer simulations. . . . The scientific “facts” that result from such simulations are testimonies to the networked actions of scientists and computers. (p.102)

This alerts us to another profound ontological shift associated with the exponential growth of ICTs. While their networking power might allow the creation of new ontological categories by association, computers are humans’ co-partners in the active production of new forms of knowledge and new ideas about the “being” of entities in the world. These ideas need further exploration.

**Virtual reality and the traditional curriculum**

Burbules (2000) asks “In what ways does the virtual represent a category of being and action different from the conventional dichotomy of real versus the artificial or imaginary?” (p.37, emphasis in the original). While he sees dangers in the use of online technologies for learning, he also sees “exciting educational possibilities” (p.39). For example, new “visualization technologies” allow information to be represented in experimental ways that are not text-based. Along with these comes “virtualisation” or access to learning that can only be accessed online. Through visualisation and virtual simulation activities learners can “observe or measure phenomena they could never witness first-hand” (p.39). While it is easy to see why
teachers might welcome such powerful aids to their students’ imaginations, interesting ontological challenges are raised.

Earlier in this section the idea of ontological reversal was introduced (Dahlin 2004). Using ICTs, the empirical realist ontology of science as it is usually presented to students could so easily be reinforced by simulations that “thingify” the entities of science ever more vividly. If traditional teaching methods already create a problem when the abstract is taken to be more real than the real, what will be the impact of virtual simulations and what should teachers do about this, if anything? I have not seen this NOS question posed in the science education literature, and I am now going to attempt a possible answer, drawing on insights from the social studies of science.

From science studies to the “knowledge society”

In his book Pandora Hope, Latour (1999) presents an analysis of the theory-building actions of two different scientists (a botanist and a pedologist) whom he accompanied as they worked together during a fieldtrip in the Amazon Basin. The scientists wanted to understand the dynamics of changes in soil profiles at the boundary between forest and savanna. For his part, Latour wanted to know how they made the ontological conversion between the real world and the scientific papers they would ultimately write. He produced a model for understanding this process that he argued overcomes the philosophical difficulties with the nature of “reality” introduced in the first half of this section.

Latour describes “a series of passes across the difference between things and words” (p.69, emphasis in the original). At every “pass” some aspect of (real) “matter” became a “form” (in language or in some contrived arrangement of its original state). For example, the messy soil of the forest floor crossed one “pass” to take the form of small cubes of soil in a special suitcase called a pedocomparator. The real cubes in the suitcase took the form of a pattern as the pedocomparator was filled, because they had been placed in a careful order—transect points on one axis, soil depth on the other. This real pattern in turn took the form of a table when numbers were assigned to the cubes according to a colour chart of soil types. In this way the real soil, via a series of passes, had been transformed into tables of numbers on paper that could be taken anywhere in the world (and indeed did return to Paris with the scientists).
I have described this example to illustrate the points Latour makes about this process of transformation. His first point is that a “gap” in reality is created between matter and form at every “pass”. But as long as the entire chain of transformations remains intact the process is reversible and can be traced from either end—that is, the actual world at one pole, and the scientists’ “circulating references” (tables, graphs, diagrams, scientific papers, and the like) at the other. As Latour puts this, “Truth value circulates here like electricity through a wire, so long as this circuit is not interrupted” (Latour 1999 p.69, emphasis in the original). He suggests that traditional debates about reality reflect the deliberate “erasure” of all the “mediations” (i.e. matter to form transformations) so that only the two poles are presented—the world on one hand, language and its supporting devices on the other. As Bruner would say, all narratives have been washed away (Bruner 1986). This is what perpetuates the binary and results in the traditional ontological dilemma of determining truth in relation to reality. But with Latour’s model, so long as the whole chain remains intact, the world and the products of the mind form a demonstrable continuity.

One NOS implication from this very different ontological account of reality is that, in constructing my account of Latour’s ideas, I needed to write a brief narrative to describe the chain of transformations, thereby making them accessible in everyday modes of thought. I think that most students, shown this chain from start to end—told the “story” behind the theory development—would find the ideas much more accessible. Indeed, as briefly outlined in Section 2, there have been many recent calls for the use of “narrative pedagogy” in science education (summarised by Solomon 2002) although it has not always been clear exactly what form such narratives should take, nor what primary purpose they should serve (Gilbert et al. 2005). Gilbert et al. suggest that use of narratives could be seen as a stepping stone towards learning to think and reason in logico-scientific modes of thought. To that I would now add the potential to use this type of story of knowledge transformation, as developed by Latour, to introduce ontology per se into the teachers’ conversation with students about what is real and what can be known, whilst avoiding the perils of relativism. But we haven’t quite got to the means of doing so yet.

Latour has more to say on the nature of the relationships between the two poles and all the mediations that take place in between them. Starting from the “real world” end of the chain of transformations there is a reduction in messiness, particularity, and...
distracting detail. The abstraction that makes science so difficult for many students is underway. But Latour sees the whole process as a “dialectic of gain and loss” (Latour 1999, p.70). With abstraction comes a new type of richness—what he calls amplification. The phenomenon being investigated gains properties such as standardisation, relative universality, and ability to circulate.

Moving beyond binary thinking, Latour now describes phenomena from a very different ontological perspective. They are “what circulates all along the reversible chain of transformations, at each step losing some properties to gain others that render them compatible with already-established centers of calculation” (Latour 1999, pp. emphasis in original). I think this type of analysis provides a way to accommodate human thought and theory building within a world that is “really real” without in the process raising the spectre of relativism. Latour himself describes his analysis as an important step towards a more realistic realism.

I think that teachers might more readily adopt this approach to NOS if they were provided with the resources to support it. Reverting for a moment to the assumptions of deficit theorising, they would almost certainly deepen their own science knowledge, since their own education is likely to have focused on only the end product of the amplification stage (Gallagher 1991 ; Thoermer & Sodian 2002). (At least, the end product for now. Latour makes the point that the chain of transformation can potentially stretch indefinitely in both directions as scientific inquiry proceeds.)

Another benefit is that here we have the means to reframe the dilemma of ontological reversal. Students could more consciously use the abstract entities of science in their explanations, treating them as if they are really real, whilst knowing where they had actually come from! In the same vein, logico-scientific modes of thinking might become more accessible because students see how they are gradually put into place along the whole chain of transformation. The issue of ontological reversal and the use of virtual learning aids can also potentially be resolved. Few students will be able to follow scientists in their work in the way that Latour has for many years now (see, for example, Latour & Woolgar 1979). Nor, given the theory-laden nature of observation (Millar & Driver 1987), would they be likely to see what he sees if they did. The use of virtual technologies to tell stories of science-in-the-making could
make chains of transformations come alive for students, in the same way that Latour made the story of a fieldtrip to Brazil come alive in the pages of his book. Additionally, if the fact that such observations are theory-laden is explicitly addressed, the interplay between existing theory, empirical investigation, and new theory building could become much more transparent.

When I was a teacher educator, the “alternative” science programmes provided for students who were “not bright” always worried me. I watched student teachers present watered down abstractions, using material provided by their associates, and indeed by our own national association of science teachers. I felt that such approaches made science even less accessible and students were often bored and disengaged. If they did somehow succeed in making an interesting connection, they were likely to be accused of “off-task” distraction. I had no immediately workable solution and, in the face of the many challenges presented to beginning teachers, held my peace. This dilemma, too, I can see being productively addressed with the sorts of materials that would need to be developed to take account of Latour’s chains of transformation.

**Actor networks and pedagogical possibilities**

Latour has presented an equally comprehensive critique of the binary between nature and society, created, he argues, as part of the modernist settlement of the Enlightenment. In his earlier book, *We Have Never Been Modern* (Latour 1991), he analyses issues of relativism, using modern comparative anthropology as an inquiry tool. As he sees it, relativity is a matter of extent rather than actual difference of kind:

> Modern knowledge and power are different not in that they escape at last the tyranny of the social, but in that they add many more hybrids in order to recompose the social link and extend its scale. Not only the air pump but also microbes, electricity, atoms, stars, second-degree equations, automatons and robots, mills and pistons, the unconscious and neurotransmitters. At each turn in the spiral, a new translation of quasi-objects gives new impetus to the redefinition of the social body, of subjects and objects alike. (Latour 1991, p.109)

Latour argues that the work of the “modernist settlement” has been to push nature and society further and further apart as opposing poles. The discoveries of science have been used to create new “hybrid” entities, leading to ever-larger technological networks that invisibly maintain the separation of these two poles. Latour describes the work of science in doing this as “purification”, and his analysis includes the idea
of deliberate erasure of the mediations of scientific inquiry (see above) as the means by which this is achieved.

Latour argues that the invisibility of the technological networks of “quasi-objects” or “hybrids” has allowed them to proliferate unchecked. Making these networks visible and giving up the nature/society binary will, he says, help us address pressing environmental issues whilst also introducing a “relativist relativism” (p. 113) which is “more modest but more empirical”. This type of relativism makes visible the work of science in creating “asymmetries and equalities, hierarchies and differences” (p. 113), in ways that can be documented and described. Such network analyses are related to, but extend from, the idea of circulating chains of reference described above.

Showing how such networks might be identified and described, Latour extends his analysis in *Pandora Hope* (1999) to describe an alternative model for a more “realistic rendering” of how science acts in the world (p.100). Rather than surrounding a core of science with a “corona of social contexts” (p.92) this new model posits four loops that have to be taken into account simultaneously, with a central series of “links and knots” to tie them all together. These four loops are:

1. The “mobilization of the world”, as outlined above, through the instruments, equipment, fieldtrips and, in the case of social sciences, surveys.
2. “Autonomization” (pp.102—103) in which scientists from the same field debate, form criteria of relevance, create experts and tell the history of theory building in their field through the written accounts that are produced.
3. Creating “alliances” (pp. 103—104) by placing the discipline in contexts that get others sufficiently interested to ensure supply of money and other resources needed to keep the field alive and active.
4. “Public representation” (pp. 105—106) requires scientists to work to ensure that new scientific discoveries become part of the fabric of society. They do not stand outside that society themselves, which can in turn, influence the ways they conceptualise and build their field.

Holding all four loops together are the links and knots of the *concepts and theories* that are the “pumping heart” of science—the “very tight knot at the center of a net”
Latour asserts that all these parts have to be understood for concepts and theories themselves to be understood:

But when science studies seeks to understand the centrality of the conceptual content of science, it tries first to see for what periphery this content plays the role of a center, of what veins and arteries it is the pumping heart, of what net it is the knot, of what pathways it is the intersection, of what commerce it is the clearing house. (Latour 1999, p. 107, emphasis in the original).

This is a very different ontology of science “concepts” to the more familiar abstractions of Dahlin’s “ontological reversal” or Ogborne and colleagues’ “ontological zoo” (Dahlin 2004; Ogbon et al. 1996). The theoretical entities are still here, but they are caught up in a web of real-world relations that does not differentiate between the physical and the social. What might such a web look like in practice? This question is taken up by James Gaskell (2003) as a solution to the tricky contemporary issue of how science education can respond appropriately to the challenges posed by multiculturalism. For Gaskell, debates about “relativism” in accommodating other worldviews in science education are unhelpful. Rejecting the idea that science is determined solely by nature does not have to mean accepting that it is determined solely by culture where “what is knowledge is dependent on relative social power” (p.242). He suggests that the dilemma be resolved by using “the language of actor-networks” (p.242). From this perspective, the credibility of knowledge is based on the size and strength of the networks it invokes:

For example, the difference between the weather forecast from the weather office and the forecast of an elder who had lived in a particular location all his or her life is not that one is more or less often correct on a particular day for that particular location. The difference is the number of people and bits of data from around the globe associated with thousands of weather balloons, boats, weather stations, and other instruments that have been accepted as reliable and brought together in readable forms compared with a smaller number of human and nonhuman associations in the local environment. (Gaskell 2003, pp.242—243)

Both the local and the weather forecaster employ data from an extensive range of experience. The local may well have more local credibility because of knowledge of specifics of local conditions, but the forecaster is able to draw on much wider and stronger networks, with a more explicit theoretical underpinning, to make more general forecasts for a much wider area. Thus the question Gaskell says, following Latour, is one of “sociologic” not “logic” per se. I like this example because it carries immediate pedagogical possibilities. I can see me as a teacher teasing out both sets of
networks to address the question of “which is better” in a way that has no need to adopt a universalist perspective, without in any way compromising the power of science at work in the world. Quite the reverse, in fact. As Latour would say, we have more reality, not less, when we employ the tools of science studies (Latour 1999). In Section 7 I attempt such an analysis in the context of debates about the theory of evolution.

There is potential for this type of pedagogical approach to address a completely different, more “traditional” science teaching dilemma. John Wallace and William Louden (2003) use three case studies of teaching dilemmas to discuss the uncertainties and ambiguities inherent in the assumption that it is possible to teach for “understanding”. One dilemma is stated thus: “Does specialist language interfere with understanding, or construct it?” (p.552). At the heart of this dilemma lies the seeming contradiction of allowing students to communicate their science ideas in the narrative mode when the actual aim is to learn logico-scientific modes of communication. They note that many words used in scientific texts—even quite ordinary words such as “bending” and “media”—“form part of a network of interlocking definitions” (p.555, emphasis added). Students need to understand how words are used in specific contexts, and to be aware how new definitions and theories build on those already accepted as part of the genre. Until they understand these conventions, they cannot be said to “know” the science:

Finally, to understand Snell’s law as physicists understand it requires students to operate within the system of language and values that constitutes the discipline of physics. (Wallace & Louden 2003, p.556)

When learning about chains of translation such as those described by Latour, teachers could emphasise the way the substance-form changes are captured by specialist use of words. This vocabulary is underpinned by all the previous empirical work and theory building in which it has been invoked, i.e. a network of interlocking definitions. The words have both a history and a specificity. If tracing even a few such networks led students to ask “What does this term stand for in this context?” then this particular understanding dilemma might be on the way to being solved.

One critique of network studies is that they can be misinterpreted as describing actual structures rather than the fluid and ever-changing webs of connections and alliances.
that the network theorists actually intend. One response to this has been to use the more organic concept of rhizomes, with one science studies theorist (Michael Lynch) once suggesting the field should be called “actant-rhizome ontology” (Spinuzzi 2003). At least one science educator has begun to explore what such “rhizomes” might look like in teaching and learning although this work is still rather speculative, and located more at the tertiary than the school level of learning (Gough 2004b, in press).

**Cyborgs and other ontological challenges**

Recent feminist critique of science has taken up similar ideas to the science studies theorists. For example Sandra Harding (1993) says there is no such thing as “pure nature” or “pure science” and calls for a “strong objectivity” that includes a “logic of discovery” (p. 18). This idea of strong objectivity looks very like what Davis and Sumara (2005) call “interobjectivity” in the systems sciences and matches Latour’s calls for more empiricism, not less in the description of actor-networks.

Donna Haraway (1991) also sees a “damaging distinction” between pure and applied science, and between nature and culture. Such distinctions have been used to “justify the double ideology of firm scientific objectivity and mere personal subjectivity” thereby providing “an important buttress of social control” (p.8). This introduces the idea that the entities created by science do political work in the world, as captured by the term “ontological politics” (see, for example, Law & Urry 2002). This idea has interesting overlaps with the idea of the “depth ontology” proposed by the critical theorists in the social sciences, but moves beyond that position to emphasise the non-duality of nature/society as well as mind/world. I return to the links between ontology and politics in Section 6.

As Latour would say, humans and non-humans are drawn into one great collective (Latour 1991). And things that are not human, yet not “natural” either, are brought clearly into view. Some of the technological artefacts science has created are now explicitly recognised to be part human, part machine, or “cyborgs” (Haraway 1991). Gough (2004a) identifies three types of cyborgs.

There are the imaginative or “virtual” cyborgs that populate movies, television, comics, and graphic novels—Blade Runner, RoboCop and the like. Echoing my
earlier discussion of the problems of binary thinking, Gough says that the “cyborgs populating SF [science fiction] dramatize the deeply ambiguous status of categories like man, woman, human, artefact, member of a race, individual entity or body” (p.100). Such cyborgs are a vivid part of young people’s reality and can form engaging contexts for the study of science and the new ontological categories it continues to bring into being (Gough 1993).

Then there are “theoretical constructions of cyborgs” that combine qualities of humans and animals. These are used as foci for debate in contemporary philosophy. For example, Haraway described how existing ideas about human sexuality influenced methodologies and assumptions of empirical studies that led to the “production” of primate behaviour in ways that then reinforced existing human sexual politics as natural (Haraway 1989).

And finally there are the many people who are already cyborg in some way—like me sitting at my computer shaping this discussion, drawing on my EndNote memory, and reminding myself that I need to make an appointment to get my eyes checked and my spectacles strengthened. While they do not use the term cyborg, Davis and Sumara make a link between these ideas and the concepts used by complexity theorists: “The notion of interobjectivity presses attention to the roles of the biological within the human and of the human within the more-than-human world” (2005, p.317).

**Gough (2004a) calls for the widespread use of cyborgs in science education:**

Cyborgs are now so ubiquitous, both imaginatively and materially, that they cannot be omitted from any intellectually honest version of the curriculum, the “collective story” we tell children. (p.95)

He sees Latour’s actor networks as cyborg positions (p.102) and draws links between complexity sciences and the widespread use of computers and other technologies. For Gough, narrative pedagogies should take their cue from postmodernist theory, but transcend its scepticism by using network inquiry methods. He says that postmodern fiction can be used to raise important questions about the nature of multiple worlds, their manner of constitution, and their differences. Such a focus on multiple realities is the “ontological dominant” of postmodern fiction, whereas
modernist fiction asked essentially epistemological questions, seeking the “one true story” (Gough 2004a, pp.92—93).

Literary theorists David Gordon and Gad Alexander (2005) also identify ontology rather than epistemology as the system we need to elicit to read postmodernist fiction. They say postmodernist literature often incorporates a different view of the nature of time, using “parallel temporalities” (p.150) in juxtaposed universes. They say that such fictional reconceptualisation of time both reflects and has influenced “profound cultural changes in our era” (p.150). Network theorists John Law and John Urry also talk about “pluriverses” that are:

different realities with different registers, different rules, different ways of thinking and knowing. There is multiplicity but also interaction. For our argument is not that multiplicity is a matter of fragmentation, of ‘anything goes’, or of realities like bubbles which have nothing to do with one another. Rather it is a continuing set of interferences between different realities. The picture, then is of irreducible realities that nevertheless interfere and fundamentally affect one another. (Law & Urry 2002, p.7)

In a network analysis of sweeping scope, Manuel Castells (2000) theorises how such very different realities have come about. He implicates ICTs, with their power to transfer information and money very rapidly around the world, in the rise of what he calls the “networked society” of the “information age”. The ability to process information in real time anywhere in the world, regardless of where it originated, is leading, he says, to changed views of time. The networked nature of connections between individuals, no matter where they may happen to be in actual space, is creating new issues for identity construction. But, for education, perhaps the most important ontological change he describes is the transformation of views of knowledge itself. Rather than being seen as a noun - a thing to be acquired in learning - the metaphor of knowledge-as-a-verb - something to be used, not stored- now prevails.

Jane Gilbert (2005) discusses the profound implications for education of this change to the status of knowledge within the so-called “knowledge society”. For her, one important imperative is that students should develop meta-awareness of the traditional disciplines—that is, learn how and why knowledge is constructed in different ways in different fields so that they, too, can learn to become knowledge generators, not just knowledge consumers. She also sees a need for a much more
explicit focus on identity, and of each individual’s potential for multiple positioning in the world. This call for meta-level thinking could be read within a traditional epistemological framework to mean NOS as usual, as in Section 2. Or, following the ideas introduced in this section, it could mean the introduction of approaches we have not seen widely used up until now. The call for a more explicit focus on identity construction certainly sits more comfortably with the new ontologies. But whatever happens, changes will have to play out against the reality of teachers’ work. As I next outline, any attempts at NOS reform will need to make sense and feel safe for teachers, an issue that I believe has been largely ignored in the NOS literature to date.

NOS uncertainties and relativism
A favourite rhetorical device of neoconservative critics of educational reforms is to fling the accusation that “facts no longer matter” and “anything goes” in a “dumbed down” curriculum. Any deviation from scientific realism, with its associated view of curriculum as a shopping list of content, is seen as a threat to the system itself and to students’ learning. Nor is this tension confined to curriculum, or to those with an ideological axe to grind. For example, in a carefully measured analysis, David Phillips (1995) identifies the tendency towards relativist thought as the “bad” face of potentially useful constructivist teaching reforms. Deviations from scientific realism in science education can expose would-be reformists to accusations of relativism that they may not be well placed to know how to ameliorate if the concern is warranted, or counter if it is not. In view of this, I must address the issue of how safe it would be to ask teachers to follow new philosophical pathways in their own learning.

Perceptions of relativist thinking are an issue for all ontological positions that involve some form of human judgement to be taken on trust. This is an especially acute philosophical problem for idealist ontologies. Who is to say what is more real or true? As already stated, Latour sees idealism as the ultimate folly of the wrong pathway that was taken when mind and world were pushed apart by binary thinking. In his experience, this situation has led serious people to ask “Do you believe in reality?”—a question he finds understandable but dangerous (Latour 1999). I think science teachers sense the same danger, if not with the same deep understanding of its causes. Early in my thesis journey I began to wonder why everyone I knew
personally who had embarked on a NOS learning journey was, like me, no longer a school teacher of science. The more I pondered on this question, the more it bothered me, to the point where continuing with my original focus became an act of optimism that some solution to the relativist dilemma would present itself if only I worked hard enough.

Looking back, I can see that my focus was in the wrong place. While ontology quietly did its work in the world, structuring every aspect of a teacher’s “ontological zoo” of science entities and their “being” in that role, my focus was on epistemology, and what might be done to change that. To that starting place, I must temporarily return.

Realist thinking is a deeply entrenched aspect of science teachers’ NOS views. Section 2 introduced Claxton’s (1997) assertion of a “widespread assumption that science does not just own the epistemological high ground, but is actually the only (valid) epistemological game in town” (p.75). For some science educators, feelings run high and intemperate positions are expressed when there is a suspected case of relativist thinking to be held at bay (see, for example, Matthews 1995 on the issue of constructivism and science teaching). Anger is an interesting emotion to explore and I well remember stages of feeling angry and unsettled in my own education in the philosophy and sociology of science while I was studying for my MEd (Hipkins 1998). I now outline a possible reason for these types of responses, from teachers in particular.

**Theories of epistemological development**

In their summary of widely discussed theories of epistemological development, Barbara Hofer and Paul Pintrich (1997) identify similarities and differences in the developmental sequences postulated for three major theories. These are William Perry’s 1970 scheme of “Intellectual and Ethical Development”; Mary Belenky’s 1986 scheme of “Women’s Ways of Knowing”; and Baxter Magdola’s 1992 “Epistemological Reflection” model. All three studies identified a series of epistemological development stages that suggested a process of qualitative reorganisation of personal meaning making over time.
The first of Perry’s stages describes dualist, absolutist, right and wrong views of the world. Belenky and her colleagues extended this insight to show how women’s epistemological development is intertwined with self-concept. Accordingly, their scheme begins with several dualistic positions, in which women move from passive “silence” to a right-and-wrong judgement of “received knowledge”. Magdola similarly describes a first stage of “absolute knowing”. While these positions are about how ordinary people say they know things in general, rather than about how scientists say they know the world in particular, ontological similarities to empirical realism are apparent. There is one correct view of reality, if only we can find it.

The next cluster of stages charts the development of what Perry calls “multiplicity”—belief in absolute authority is eroded to the point that the individual comes to believe that all views are equally valid and that each person has a right to their own opinion. Hofer and Pintrich (1997) note strong similarities between Perry’s multiplicity stages and those proposed by Belenky, who adds the idea that women go from believing everyone can be right to the recognition that everyone, including themselves, may be wrong, and that care is needed in reaching the truth. Baxter similarly identifies stages when authority is questioned as the only source of knowledge and knowers begin to hold their own opinions as equally being valid. Here the similarity is to idealism—that is “reality” has moved to the opposite end of the ontological continuum. This type of thinking has been called a form of naïve relativism (Elby & Hammer 2001) and it has been demonstrated to limit school-age students’ ability to bring NOS insights to bear on the discussion of socio-scientific issues (Zeidler et al. 2002). It seems to me to be a position science teachers would regard with great suspicion.

The next development, described by Hofer and Pintrich as the “watershed” (p.91) of Perry’s scheme, represents an interesting move away from the extremes of naïve relativism towards a contextual relativism in which individuals perceive knowledge as relative, contingent, and contextual. Belenky et al. call the equivalent stage “constructed knowledge”. Knowledge and truth are seen as being contextual and actively constructed, with the knower being an intimate part of the known. Where Perry concentrated on the nature of knowledge and truth, Hofer and Pintrich point out that Belenky et al. have focused on the source of knowledge and truth. However in both cases there are two key shifts at this third group of stages. One shift is from a
rather extreme relativist ontology to a sophisticated and qualified form of contextual relativism. The second strongly linked shift is towards a clear epistemological differentiation between what is known and different ways of knowing. Baxter charts a similar progression through “transitional knowing”, in which the uncertainty of knowledge is beginning to be accepted, to “independent knowing” in which “contextual knowers” are able to construct an “individual perspective by judging evidence in context. Expertise itself is subjected to evaluation” (cited in Hofer & Pintrich, p.98). The epistemological orientations described here seem closest to the ontology of critical realism, although the correspondence is not without problems that cannot be resolved from within these traditional ontological perspectives. The point to be made for now is that we have moved back towards the centre of an ontological “reality” continuum.

In all three schemes, the intermediate developmental stages represent epistemological positions that are more relativist than the final stage(s). It appears as if the baby of referential judgement has gone out with the bath water of ontological certainty before some more moderate epistemological position could be reached. Significantly, from the point of view of the argument I am developing here, very few of the many people collectively interviewed in these three longitudinal studies actually reached and held the final epistemological position with any consistency (Hofer & Pintrich 1997). Is it necessary, as the similarities in all three theories seem to suggest, to move first through a very relativist phase before reaching the calmer waters of a more sophisticated epistemological position? If this is so, then the characteristic track of undergraduate learning may ensure that the great majority of science students simply never take that learning risk at this point in their careers. There are several possible explanations for this dilemma.

**Epistemology and university learning**

There is a tendency for first year university courses to “cover” large amounts of material in large lecture theatres where interaction between students and lecturers may be restricted, if not impossible. The lecture style of such learning experiences is most likely to employ the logico-scientific communication mode, adding weight to views of science as an unproblematic body of content knowledge if the rich experiences of the knowledge construction have been set aside. And as outlined above, such teaching methods may foster ontological reversals that further entrench
“thingified” views of NOS. It could be that this influence happens to be very strong just as a student might be about to make the move from realist to idealist thinking—from the first cluster of stages to the second on all of the models outlined above.

One objection to this view is that a more constructivist pedagogy is perfectly possible, if it accords with the teacher’s philosophy (Davis 2004; Yore 2001). University lecturers across a range of disciplines, including the sciences, can hold very different metaphors for their teaching role, some more constructivist than others (Martin & Luecktenhausen 2005). However, many tertiary science teachers seem to hold strongly realist views and do present science as a body of facts (Gallagher 1991; Thoermer & Sodian 2002). After interviewing scientists about their formal writing practices, Yore and his colleagues observed that some who held “nontraditional” views of science in informal conversation nevertheless “used language associated with empiricist, positivist or rationalist interpretations of science” in their formal written and spoken responses (Yore et al. 2004, p.339). Is it possible that the act of organising knowledge into the structure of a formal lecture in the logico-scientific mode (or a written report) lends itself to an ontological and epistemological re/presentation that is more strongly realist? These are circumstances in which any hint of relativism might be resisted, either because students are being taught established theory, or because the scientist must present a compelling argument for their peers. Whatever the dynamics, there are obvious implications for science teaching at all levels and this is a question to which I will return.

In the meantime, I am suggesting the possibility that the type of learning experienced in an initial tertiary education in science may stall, and in some cases completely block, epistemological development at a critical stage. The pathway set out above rings very true for me—indeed reflection on my own experiences was what alerted me to possible significance of the common thread in all three schemes. For many years I was that realist didactic teacher, even though I valued input and debate from my students and generally enjoyed very good classroom relationships. For me, the “watershed” began with debate about standards-based assessment which took place within New Zealand education circles during the 1980s. For the first time I began to see purposes for my teaching other than the efficient acquisition of “content”. Hard on the heels of that development came a new curriculum document (Ministry of Education 1993), underpinned by findings from the Learning in Science Research
Project (see, for example, Osborne, R. & Freyberg 1985) and the challenging new ideas of constructivist teaching. When I look back on those years I can clearly recall my initial shock at each radical new proposal—and then I decided (though not consciously) to “throw the baby out with the bath water”. For a time—not too long—I became that very relativist thinker. I was, however, not usually aware that I was arguing an extreme epistemological position until challenged by more knowledgeable mentors. (I was by then completing Master of Education studies and was working in teacher education). Finally, after several years of intense intellectual struggle, I reached the relative “safety” of a more contextualised position.

This position, too, I have now left behind, with the help of the sociologists of science and complexity theorists. For now, however, I have outlined the NOS problem using the tools of inquiry of modernist science (including ideas about sequential development) because they fit with “common sense” thinking and allowed me, early in my thesis journey, to make retrospective sense of my own experience. It seems to me that the hazardous, unsettling epistemological journey I have described is a major stumbling block to taking any conventional philosophical route to understanding the intention of reforms in science education. Borrowing a metaphor from Catherine Loving, I now see that the majority of science teachers, so firmly inculcated in realist views, will always see relativism as a slippery slope (Loving 1997) with which they do not want to flirt. As long as they feel like this, they are unlikely to want to unsettle their students by portraying any version of science knowledge as uncertain, contingent, and value-laden.

In addition to this, the ideology of mass schooling requires teachers to present a curriculum from which uncertainties have been deliberately suppressed. The deeply entrenched “hidden curriculum” perpetuates settled knowledge in ways that are differentially advantageous to certain sectors of society (Apple 2004). Either way you look at it, the epistemological and ontological status quo must feel safer than the very new ideas about ontology that I have introduced in this section.

**Looking ahead**

This analysis has arrived at a very different view of ontology from the one where it began. In the place of the universal certainties of the concepts, laws, and grand
theories that are the products of science, we have a much more dynamic and complex view that nevertheless is also claimed to be both empirical and theoretical. The abstract entities of the ontological reversal have been replaced by chains of circulating references, complex systems, ever-growing actor networks, cyborg manifestations of human-nonhuman interfaces, and the prospect of inquiry methods that can accommodate multiple realities without recourse to the confidence-sapping relativism of modernist philosophy.

How ought teachers respond to these profound shifts, if indeed they can? Might a different, more ontologically-focused, understanding of their current “reality” offer possibilities for change? While I have indicated one pedagogical possibility from the work of Bruno Latour, I do not see this as a “cure all” but rather as just one approach to the NOS dilemmas science education faces. I will return to this discussion in the final section of the thesis. More immediately, I turn next to the implications of the ontological turn for methodological issues in my own research.
4. Doing research in a pluriverse

Introduction

This section explores the practical/theoretical decisions I have made throughout the thesis journey. Attempting to retrospectively write a methodology that is an adequate response to the issues raised in Section 3 has been an interesting challenge. Rather than attempting to tell a linear, tidy “purified” story (Latour 1991, p.478), I hope to tell multiple, overlapping stories that better reflect “making a mess with method” (Law 2003) as the story of the real research process unfolds. Borrowing from network theorists the idea that there are multiple realities rather than just one, I discuss three different broad theoretical framings I have drawn on during the production of this thesis. Each has its own ontological assumptions and challenges, and I explore their points of intersection and significance for my work.

Three worlds, three stories

Questioning the neatness of tidied-up accounts of method, Law says he is not making “an argument about epistemology—about how to see (a single) reality. Instead it is about ontology, about what is real, what is out there” (p.6). What we may need to deal with in social research, he says, is a “shape-shifting reality” (p.2) that cannot be described in one unified account. In this section I respond to this challenge by drawing on three different ontological perspectives. In part this is a response to the dilemma of changing the theoretical lens through which I saw my work, not once but several times, as the thesis unfolded. Such are the challenges, but also the opportunities, of an extended learning journey.

I began the project within a humanist framework, although I was not then aware that there could be any other. Part way through I discovered the social studies of science, the ideas of the network theorists, and the (for me) very different philosophy of the American pragmatists. At this point, ontological concerns came to the fore, although of course they had always been there, hidden away in realist perspectives. And all

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4 I have written the pair this way to signal that I do not want to treat them as binary but rather as two faces of the same coin.
around and between these two very different worlds oozed fragments of postmodern theorising, bringing this third theoretical world, with its tendency towards ontological idealism, into uneasy juxtaposition with the ideas of both humanism and network perspectives. I briefly survey all three worlds here, before giving the more thorough methodological accounting required of any thesis writer.

Writing from a feminist perspective Elizabeth St. Pierre discusses key “themes” of humanism, to which “post” anything perspectives are a critical response. These themes include: the unproblematic assumption of a correspondence between language and the things in the world that it names; a belief in reason and rationality as the arbiters of truth, with the accompanying mind/world binary; belief in the “scientific method”; a belief in each person as a unified “subject” endowed with an inherent agency to act in the world; and the notion of inevitable “progress” and the emancipatory nature of ongoing change (St. Pierre 2000). I now realise that, in taking some of these for granted at the beginning stages of my research, I was far from alone:

Humanism is in the air we breathe, the language we speak, the shape of the homes we live in, the relations we are able to have with others, the politics we practice, the map that locates us on the earth, the futures we can imagine, the limits of our pleasures. Humanism is everywhere, overwhelming in its totality; and since it is so ‘natural’, it is difficult to watch it work. (St. Pierre 2000, p.478)

So there is a story to tell about a project that started off with a methodology untroubled by humanist assumptions about language, subjectivity, autonomy, and progress. (I was already aware of challenges raised by the Cartesian duality and ideas about the universality of a scientific method.) That story did not come abruptly to an end when I began to focus on challenges raised by the ontological turn, or by my early attempts to deal with the uncertainties raised by postmodern and pragmatist theoretical frameworks. The epistemologically-focused questions I designed initially were, by and large, the interview questions I actually asked. Given the pervasive nature of humanist thinking, it seems entirely predictable that my participants also heard and responded in this vein. How could they do otherwise? From start to end of the thesis journey, humanism is ever present. This is one of my three methodological worlds.
Part way through the research I began to realise that the questions that elicited the richest insights into my participants’ thinking were the “warm-up” contextual questions that began the interview. What is more, where they could, my participants shied away from the more abstract questions to bring the conversation back to the contexts and experiences of their fellowships. At these times I had the strong feeling that the interview was on surer ground. Later I came to realise that this experience had been described by St. Pierre in terms that resonated with the new theoretical directions I was beginning to explore:

This question [initial research question] clearly emerges from humanism, given that it assumes that knowledge is something stable that can be located and described and that it had an origin. I quickly discarded it when my participants sidled out of it and, rather than tell me what they knew, described their daily practices of living and how those activities had changed through their lives. They responded to my epistemological questions with ontological answers—it was not the knowing that concerned them but the doing, the nature of their days. (St. Pierre 1999, p.272, emphasis added)

The nature of my participants’ days had more to do with the science research they pursued in the first year, and the settled science they taught in the second, than with any fancy epistemological ideas. With their realist ontologies and their passion for “doing” science teaching as initiating students into what they knew to be “true”, most of my planned questions must have seemed far removed from my participants’ daily concerns. For me, the “ontological turn” had arrived, erupting into my consciousness through the vivid analyses of the science studies theorists, which resonated with my already existing interest in complexity theories and the systems sciences. A new universe of networked possibilities opened up and this is the second of the worlds I discuss.

Around the same time, I stumbled upon the narrative methodologies of life history research. Here were more possible intellectual tools for the methodological “mess” I was building, and so I overcame my longstanding hesitancy to plunge further into the last of my three universes—the relativist, postmodern world. Ivor Goodson and Pat Sikes (2001) say that life historians are “not, inevitably, postmodernists, poststructuralists, feminists or relativists” (p.39, emphasis added). The use of “inevitably” suggests that this is how they are most often positioned. Besides which, some of the more recent ontological developments outlined in Section 3 take this as their point of departure. For example Gough (2004a) advocates the use of autobiography and narrative in curriculum inquiry, not as these might have been used
in humanist research methodologies, with their assumptions of a singular, fixed, and essential self but rather with the postmodern intention to improve our own understandings of curriculum and of ourselves as curriculum workers (p.90). Like Gough I am curious to see where this journey might lead, and see great potential in this type of research for writing stories that will speak meaningfully to classroom teachers.

Finally, in 2005, with the completion of the theoretical analysis in Section 3, came some sense that a resolution of these various perspectives was possible. Finally I dared to hope for the “disciplined lack of clarity” that will allow me to tell a complex story without in the process making a product that is so “pure” it is no longer real (Law 2003, p.3).

**A world of shifting networks and history remade**

Ontology is dominant in a networked world. Methodological scrutiny turns not so much around questions of how we can be sure what we discover is “real” as around the ways our research co-constructs what is real via our interactions with what is “out there”. Law and Urry (2002) call this the performativity of sociological research and make an interesting NOS link in the process:

…reality here is a relational effect. It is produced and stabilised in interaction that is simultaneously material and social. Heisenberg dealt with a version of this problem in physics: ‘What we observe is not nature itself, but nature exposed to our method of questioning’. Here there is little difference between physics and sociology: methods are protocols for modes of questioning or interaction, which also produce realities as they interact with other kinds of interactions. This means that we are not saying that reality is arbitrary. The argument is neither relativist nor realist. Instead it is that the real is produced in thoroughly non-arbitrary ways, in dense and extended sets of relations. It is both real and produced. (Law & Urry 2002, p.3)

Extended sets of relations bring with them the history of their building—what Latour calls the “historicity of things” (Latour 1999, Chapter 5) when he deals with the challenge anteriority poses science studies. Law describes anteriority as “the sense that whatever is real out there in general precedes any attempt to know it” (Law 2003, p.6). Latour explores this in the context of Pasteur’s microbes. In what way could they be said to have existed “out there” before Pasteur’s experiments demonstrated their reality? He says the common sense anteriority of naïve realist thinking requires a “retrofitting” that occurs with the “sedimentation of time”, as if
new understandings have been lying beneath existing ones, waiting to be found (Latour 1999, p.170).

There is a methodological issue here that I must address. Could I be seen, by beginning with more recent understandings of the methodological issues I faced, to be guilty of retrofitting my methods, creating an impression of a research process that was smoother and surer than the path I actually took? This is, after all, what traditionally happens in the sciences (for an early discussion of this see Latour & Woolgar 1979). In order to address this challenge transparently, and from an ontological perspective, the diagram on the next page is my version of Latour’s model for explaining how historicity is built into ideas, even as they change over time (Latour 1999). As well as addressing the philosophical point, the diagram serves as a summary timeline of the changes in my thinking about the phenomenon called NOS.

The horizontal axis at the top shows the traditional linear model of time. As the diagram shows, my research began in 2001 but the changes I explore in this methodology section did not begin to take place until 2003. The vertical bar that extends from 2003 shows the “sedimentation” process by which changes in one space (roughly a year of the research) are retrofitted to earlier understandings. Seen from the perspective of this change space, 2005 seems to come before 2003, not vice versa. However, Latour says that this is not an argument for an idealist view in which time can be reversed. Rather the diagonal line on the model, which is the vector for the two views of time—linear and spatial—shows time moving irreversibly forward.
This diagram illustrates the manner in which more recent theoretical insights may be “retrofitted” to earlier methodological decisions, making the story that emerges look linear, neat, and even inevitable. What I understand now in 2006 has been used to rescue the irreversible but far from satisfactory decisions of 2001—2003. However there is an important difference of scale and scope between Latour’s demonstration of historicity and my interpretation. He was explaining “microbes” as a powerful new idea that gradually emerged over the space of several contested years of demonstration and argumentation to remake phenomena in the world and in science. Here were the beginnings of new networks that, arguably, continue to grow in the world as new types of microbes are still variously found, exploited, feared, and held at bay. By contrast my diagram summarises only a transformation of the world of my research because ideas that were new for me were not new for others.

Nevertheless, having conferred the possibility of some historicity to my ideas, I feel better about the necessity to go back and retrospectively describe my earlier decisions. Like St. Pierre (1997) I feel as if “all the activities of the narrative—data collection, analysis, and interpretation—happened simultaneously, that everything happened at once” (p.180). The threads of 2001—2003 are still present in 2006. How could they not be? But the insights of 2006 also make it possible to rethink the
beginning years, and to see the potential that was there, even as I took some decisions I would make differently now.

**Making interview decisions in the humanist world**

My initial plan for data gathering had a distinctly epistemological feel and focus. Data collected from the eight participants’ fellowship applications gave insights into their thoughts and goals for the year, as well as details of their proposed projects. Four interviews with each person followed, one early and one late in the fellowship year, and two in the following year when the fellowship had ended and participants had returned to their schools (in one case only for a short time).

None of my volunteers lived anywhere near my hometown so each series of interviews was conducted by telephone, with the conversations taped and transcribed. Interviews typically lasted around 40—50 minutes, with the longest taking about 80 minutes. Most took place in the evening, with a few being conducted during working hours, at least during the fellowship year. Transcriptions were returned to participants for checking. A full set of interview questions is included as Appendix 4.

My initial thesis question sought to link teachers’ NOS views to their views of science teaching and their willingness to consider change along the lines advocated by would-be curriculum reformers. I knew that gathering NOS views would be just one part of the challenge, and that I would need to cast a fairly wide net. Because all my data were to be generated by teachers’ own perceptions, I needed to find ways to also ask them about a range of factors that might impact on the interplay between their NOS views and their classroom practice.

**An overview of the four interviews**

I saw the first interview as a chance to establish rapport with each participant as they introduced me to their research programme, which was then just getting underway. I also hoped to hear about their previous experiences of scientific research, why they became teachers⁵ and something of how they might represent their personal

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⁵ Specifically why they became science teachers in the case of the six secondary participants, and teachers in general in the case of the two primary participants.
experiences and views to students in the context of their teaching practice. Fortuitously, the first of these aims led me to encourage each participant to tell me the story of their fellowship, both to that date and prospectively for the year. What I saw then as the bit that I had to get out of the way before I got to the “real” (epistemological) questions, subsequently proved to be a rich source of narrative insights.

The second interview took place towards the end of the fellowship year. The questions were designed to explore perceptions of the nature of scientific investigation and knowledge building (NOS), and to seek links between these views and the richness of the fellowship experience. In response to the fellowship stories I had been told in the first round, I devised a different “warm-up” question for each participant, enquiring about their learning and progress concerning some challenge they had raised. I had noticed that several participants were feeling very ambivalent about some aspect of their own ability in relation to the research project on which they had embarked and I wanted to find out more about that. Unfortunately, I cannot include examples because the unique contextual details\textsuperscript{6} would allow participants to be easily identified.

The third interviews were conducted in late February 2003, when the teachers had been back in their schools for nearly a month. By then I was somewhat more aware of the importance of gaining an ontological perspective on their experiences, and some of my original questions were modified to ask about the world of the classroom, as they currently saw and felt about it. I wanted to find out how the transition back into a teaching role had been, and I also asked questions that probed for any possible connections between the fellowship experiences and teachers’ ongoing curriculum interpretations and pedagogical plans. The curriculum questions still had an epistemological focus.

\textsuperscript{6} The New Zealand Royal Society produces a glossy publication each year that describes the various fellowship projects and profiles the fellows. Any details of their research activities and interests, geographical locations and so on would make them very easy to identify.
I saw the fourth and final interview as a type of “reality check”. Had the fellowship experience actually impacted on classroom practice? Were the teachers able to bring new contextual stories of science to their practice? Did they, perchance, have new NOS insights that caused them to rethink ways they worked? Had the participants been able to make any changes they intended to make? Did any changes they did not anticipate happen? I could see no immediate way to make these questions “more ontological” and so I asked them as initially devised.

The challenges of asking epistemological NOS questions
At the outset I believed that the types of questions used to establish NOS views would be important to the design of the research. I was aware that reliably ascertaining NOS views is known to be difficult. Pencil and paper instruments that have been widely used in the past have been criticised on a number of grounds (Abd El-Khalick & Lederman 2000a; Koulaidis & Ogborn 1995). In an early hint of philosophical tussles to come, I read that short response questions in a true/false format can be answered in ways that do not differentiate between a “naïve” relativist type of response and a “sophisticated” more contingent form of relativism (Elby & Hammer 2001).

Addressing NOS research challenges, one group of science educators has, over time, developed an instrument they call VNOS7 (Lederman et al. 2002). There are several versions and written responses are claimed to compare reliably with elaborated interview responses. I initially included four of these questions in my second interview schedule with the intention of comparing my participants’ responses with published sample responses that contrast “naïve” and “informed” for each VNOS question. With hindsight, anticipation of the articulation of an epistemological deficit is built into such questions. Nevertheless, the things my participants said as they struggled with the deficit the questions did indeed expose, yielded useful insights for the narrative analysis I report in Section 5.

In the first interview I decided to juxtapose a teaching question about practical work with one about teachers’ personal experiences of scientific inquiry. Practical work has been critiqued, on epistemological grounds, as potentially extremely misleading.

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7 Views of Nature Of Science.
if it is represented as real scientific investigation (Chinn & Maihotra 2002). At the very least, I thought this question could identify those teachers who subscribe to the idea of “the scientific method”, which has been thoroughly debunked by Edgar Jenkins (1996) amongst others. Again, the juxtaposition strongly suggests an expectation of a deficit, as predicted by the literature review in Section 2.

**In search of an ontological perspective**

When epistemological questions are expected to measure deficits in participants’ knowledge, those questions are often kept back from participants so they will not check in advance on what they think might be asked. With hindsight I can see this influence at work when I sprang questions on my participants in the first two rounds. Most of these questions would have been better answered had my participants had time to reflect on the unaccustomed focus. I sent out the interview questions in advance for both the third and fourth interviews. By the time the third interview loomed I had also changed some questions to focus on my participants’ perceptions of the realities of the return to school, and their feelings about these.

The first interview included three questions related to participants’ views of knowledge, including scientific knowledge. I had pre-tested these questions on six volunteers and found that the closer they were to classroom teaching, the more likely they were to view knowledge as an unproblematic product—the “thingified” knowledge of empirical realism (Desaults & Larochelle 1998). Although the pre-test volunteers had not found it easy to shape answers to these questions, my instincts told me that the way each participant viewed knowledge, even if their views were not easily articulated, would be important to my developing thesis. Because at the time I did not know of any better way to probe for these views, I suppressed my doubts and persisted with their inclusion. The ontological issues they raised have been important for the data analysis, particularly in Section 5.

Elliot Eisner and Kimberley Powell (2002) draw links between the personal experiences of those engaged in scientific research and those engaged in the creation of artistic works. These links point to common features of arts and sciences that are located in the “being” of the person. Eisner and Powell differentiate between

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8 With strong encouragement from Jane Gilbert, my initial supervisor, who saw the ontological implications in personal views of knowledge long before I got there by myself.
aesthetic experiences that include aspects of personal motivation—the satisfaction and emotions experienced while engaged in the research—and *artistic modes of thought*. In the latter category they place “craft” knowledge, and include aspects such as how, if at all, knowledge other than the purely cognitive is used to make decisions. Following this line of thinking, I reasoned that a VNOS question about differences between art and science might provide evidence of each participant’s beliefs about whether or not ways of knowing other than the purely cognitive are a legitimate part of the scientific research experience. Unfortunately the ontological essence escaped the baldness of he essentially epistemological question, and for me, this question did not “work”.

Science studies theorists Amann and Knorr Certina (1990) documented the types of verbal interchanges that happen when a lab scientist looks at a freshly prepared X-ray picture of a gel-electrophoresis. They explicitly contrast the power relationships in the intense questioning of the scientist by interested colleagues (where the power resides with the person on the receiving end of the questions) with other types of social situations, including teaching, where the power rests with the person asking the questions. It seemed to me that this difference might create interesting tensions for my thesis participants when asked by fellow scientists about their research, because they are more used to the second type of questioning. It led me to shape an interview question for the third round in which I asked them about times when they had felt powerful or powerless during their fellowship year.

**Peeking cautiously into the postmodern**

By more self-consciously exploring the work that humanism does in the world, postmodernism shifts the focus of knowledge debates away from an unproblematic realism. This has methodological implications that must be taken into account, particularly for a research project with a focus on ontology. In the interests of brevity, this discussion uses the term postmodern to stand for all those theoretical positions that are critical responses to the challenges of modernity—i.e. the broad sweep of “post” (structuralism, modernism, positivism, colonialism, etc.) perspectives. As I next outline, such perspectives came to the fore at the analysis stage of my research.
Questions of identity

The interview questions provided opportunities for participants to discuss their personal experiences, beliefs, and values in relation to learning and teaching science. The traditional NOS literature includes discussions of how teachers’ identities might impact on their pedagogical decision making. For example, Fouad Abd-El-Khalick and Norman Lederman (2000a) suggest that views of self as a learner and as a teacher of science will have an impact on whether or not NOS gets taught, even by those teachers who have the requisite epistemological understandings. Jenifer Helms (1998) says that identity as a science teacher is complex. She proposes four interrelated dimensions: actions as a teacher; what the teacher thinks others expect of them (personal, cultural, social expectations); personal values and beliefs; and vision of one’s future self, of the type of teacher one wants to become. Humanism assumes a unified subjectivity or “identity” but findings such as these carry hints that things may not be so straightforward, and that teachers may have to wrestle with contradictory identity positions.

For postmodernists, every person is an “intersection” of “identity categories—race, class, ethnicity, sexual orientation, age, wellness etc.” (St. Pierre 2000, p.480). Such categories typically subsume difference under the “essence” invoked by the category name—that is, they support essentialist thinking. Here we see language going about the ontological work of shaping categories of things. This led me to ask myself whether and how essentialisation of the identity category of “teacher” might impact on teachers’ apparent willingness to change their classroom practice. My participants were all experienced teachers who became positioned very differently during their fellowship year. They became, at least, teacher-researchers, if not fully fledged scientists. Taking my cue from St. Pierre’s attention to her old ladies’ interest in “the nature of their days”, the questions I asked at the beginning of the third interview were particularly helpful for highlighting the issues raised by changing roles at the time of the return to school. However, being alert to the ontological significance of what was said—at least in terms of how the research experience impacted on the “science” subsequently produced in the classroom—required different types of research tools for making meaning from the interviews. That there would be reasonably straightforward meaning to be made from what was said, I now realised, I had initially taken for granted.
Postmodern perspectives on challenges for making meaning from interviews

James Scheurich (1997) questions the assumption that one “true” meaning can be drawn from interview data, no matter how careful the researcher is to try and accurately contextualise the transcription, nor however careful the process of analysis:

Human interaction and meaning are neither unitary nor teleological. Instead interactions and meaning are a shifting carnival of ambiguous complexity, a moving feast of differences interrupting differences. (Scheurich 1997, p.66)

The term “teleological” is used here to describe the belief that an interaction exists for the purpose of constructing meaning jointly. As Scheurich points out, both interviewer and interviewee may have many motives for their ways of acting during the interview—some consciously decided upon, some not. Some potential sources of ambiguity he names are: things that are thought but not spoken; compromising meaning for the sake of expediency if the right words are hard to find; saying what one thinks ought to be said; and dominating or resisting meaning in the conversation at certain points.

Challengingly, Scheurich doesn’t really resolve the problems he poses concerning the use of interview research, except to say that “new ways” of presenting and undertaking such research are needed. In the introduction to the book, written at a much later date than the interview chapter, he observes that “indeterminant and unconsciously driven as subjectivity is portrayed here, I have still left it basically in place as a singularity” (p.4) although he says he no longer agrees with doing so. This is a challenge I would like to pick up—if my participants’ realities are not be portrayed as “singularities”, there are implications for the analysis and the reporting of the data.

St. Pierre describes the use of what she calls “response data” as one means of taking account of the “transgressive data” that result from potential ambiguities in the interview process (St. Pierre 1997). For example, she says the researcher can be alert for the impact of emotional data by undertaking a reflexive deconstruction of their own identity in the research, including how their own “desire for validity” (p.181) impacts on the meaning made. My desire for validity in the eyes of my participants coloured some in-the-moment responses during interviews and I found myself asking
clarification questions, or offering supportive comments about, for example, “bright” students, even though this is an identity category I have seen as highly problematic for some years now. Being alert for such instances assisted my analysis of the meaning making at work in science classrooms (Section 6).

Participants’ emotions are also response data. The questions I asked about the nature of knowledge in the first interview made some respondents angry. They said they needed more time to think about them, and I found myself hedging as I introduced these questions to those interviewed later. Several participants asked if they could see what other people had said about these questions. In response I collated a selection of verbatim comments, taking care to include something from each interview participant, and sent these out with the completed transcripts. Although I invited further comment at the end of the second interview, most participants by then showed very little interest in returning to the subject. I suspect that asking to see other people’s ideas was an act of interviewee resistance (Scheurich 1997)—a way of covering up the silence that had opened up between us. On reflection, I also think that I should have done more to process the ideas before presenting them. Which leads me now to turn to the challenges of presenting interview data in a form with which other people will want to engage.

Transcription and the production of engaging data
Steinar Kvale (1996) describes the act of transcription as an important early stage of the data analysis. Transcriptions are “artificial constructions from the oral to a written mode of communication” (p.163). In Latour’s terms (1999), the step of transforming one type of reality (a conversation, with all its associated ambiguities) into another thing entirely (a fixed written text) could be described as an act of inscription—one step in creating a chain of circulating reference. It is important that this is done as transparently as possible.

Kvale (1996) suggests the inclusion in the transcription of information about the emotional conditions that pertained as comments were being made. Following this advice I included pauses, hesitations, repetitions, nervous laughter and so on. Explanatory comments were put in round brackets, repetitions typed out verbatim, and pauses or abrupt switches in the conversations signalled by the use of a dash. The New Zealand Royal Society publishes a widely distributed booklet that describes
the projects of each year’s group of teacher fellows. Consequently these project
details, and the identity of the teacher fellows, are widely known in New Zealand.
For this reason contextual detail in the interviews was generalised and placed in
square brackets.

I initially expected that a form of discourse analysis might be helpful in exploring
unspoken beliefs and values that might impact on teachers’ decision making.
Because I lacked experience in such methodology, I covered my bases, as I then saw
it, by transcribing every small verbatim detail of each interview as carefully as
possible, replaying the tapes over and over to “get it right”. By the time I came to
transcribe the third and fourth interviews I knew that I was not going to conduct a
fine-grained linguistic analysis and so I was more relaxed about capturing the main
flow of the conversation while eliminating repetitions. I also felt more comfortable
about slightly editing clumsy sentences to make their intended meaning clearer,
before I returned the transcriptions to the participants. This was reassuring for them.
The raw nature of the first two sets of transcripts had been a barrier to
communication when all eight responded negatively to what they saw as their
inarticulate communication abilities. The tidied up transcripts were, by contrast,
much more engaging. In Sections 5 and 6 the transcribed data have been further
condensed in places. Where I have broken the flow of the conversation, for example
by eliminating a brief response or question I made, or a detour from the main thrust
of the conversation, I have used three dots . . . to signal the editing.

Reflecting the postmodern concern with humanism, Patti Lather (1991) says that
discourse analysis emphasises the “productivity of language in the construction of
the objects of the investigation” (p.111). Ian Parker (1992) similarly suggests that “a
good working definition of a discourse should be that it is a system of statements
which constructs an object” (p.5, emphasis in the original). The challenge of such
analysis, as Section 2 showed, is that no matter how reflexively and critically the
analysis is carried out, the mind/world binary creates epistemological challenges for
the veracity of knowing that quickly leads to relativist dilemmas. Postmodernism’s
response to this knowledge challenge has been to devise ever more refined and
reflexive methods for carrying out the necessary analyses. One such method,
narrative or life history\textsuperscript{9} research, appeared to have interesting potential to help me address the ontological challenges I had by now embraced.

Taking ontology seriously requires a focus on being. We could think of this as a certain type of relationship between “is-ness” (Shirky 2005) and actions in a specific set of circumstances. Pointing to the potential of narrative inquiry for carrying out this type of analysis, Kathy Carter (1993) says:

The action feature of story would seem to make it especially appropriate to the study of teaching and teacher education. Teaching is intentional action in situations, and the core of knowledge teachers have of teaching comes from their practice, i.e. from taking action as teachers in classrooms. Teachers’ knowledge is, in other words, event structured. (p.7)

Both doing and being are potentially in focus here, alongside knowing. For this reason, I decided to use narrative methodology in at least one part of my data analysis.

**Narrative analysis and the translation of data**

As I was preparing this retrospective account of my methodology it occurred to me that the use of the term “transcription” invokes an image of genetics and the production of proteins, where the next step is “translation”. This is an interesting metaphor for the research story I am telling here because the ways these twin processes work in genetics can be viewed from very different ontological perspectives (Fox-Keller 1995).

Evelyn Fox-Keller’s monograph documents three underpinning metaphors for genetics, each with differently organised discipline affiliations. Starting from the simplistic linear processes of the “central dogma of molecular biology”, the field moved to the intense study of control of bacterial genes by systems such as operons. These were complicated systems, described by biophysicists whose methods were still those of linear cause and effect, notwithstanding the elegant feedback dynamics of the translation systems they described. Not until embryologists re-established a place in the field did proteomics, with associated concepts of complex and emergent

\textsuperscript{9} Again, I have conflated an extended field of methods under one umbrella in the interests of brevity.
control systems, become the more prevalent metaphor. If this story is taken as an analogy for my small study, then the use of narrative “translation” methods is most akin to the middle stage of complicated systems. There are many qualifications and limitations on the knowledge gained. Just as the operon systems of bacterial cells do not necessarily apply in multi-cellular organisms, the focus on individual teachers’ versions of their narratives is informative but selective. Provided it is just part of the story I ultimately attempt to tell, it serves as a useful methodological tool.

Writing early in the 1990s, when the methodology was relatively new, Carter (1993) warned that narratives could easily become stories of the “deficient teacher” (p.9), especially when the narrator was invisible, along with their assumptions, stereotypes, scripts, beliefs, and so on. She saw the potential for the use of story to challenge truth claims and to recontextualise teachers’ work with all its complexities, by allowing their voices to come through. Writing at the end of the same decade, Lisa Cary (1999) worried that the method could too easily lead to the production of essentialising victory narratives, especially when a teacher’s voice is reported within the epistemological frame of empirical realism. She called for a method that can “trouble the humanist foundations” (p.416) of the methodology and asked:

How can we ‘re-present’ another’s life history? What do the silences tell us? Life history projects are a mediated space that require a sociocultural construction of an individual’s life/identity. (Cary 1999, p.417)

One suggestion Cary made is that the researcher should view the story being told as a form of discourse—an “authorizing fiction” (p.417)—in order to avoid telling a “realist tale” (p.9). She recommended searching for a “nonlinear, noncoherent Self” (p.420) and drew on the network theorists Latour and Serres to suggest this self would be “relational” and created at a “confluence of fluxes” (p.421). While I found this link encouraging because it identifies a point of intersection of my three methodological “worlds”, there still remains the issue of the actual analysis tools.

Susan Chase (1995) recommended searching the text of the story-as-told for what she calls “narrative difficulties” where people seem to simultaneously hold two distinctly different, indeed contradictory, experiences of self in the experiences they recount. It is important to make space in the conversation for these “silences, gaps, disruptions or contradictions” (p.13) to emerge. Her strong recommendation is to use
questions that invite accounts of personal experiences, rather than “reports” of sociological issues, where the respondent is more likely to shape answers that anticipate what the researcher wants to hear. Fortuitously, I did invite some such stories, as outlined above. It was too late to change other questions but this paper was timely in alerting me to the possibilities of treating each person’s whole series of interviews as one big story of a particularly vivid life experience. Three of these “stories” are told in Section 5.

Margaret Olson and Cheryl Craig (2005) extend this idea to propose that “narrative tensions” are smoothed as teachers tell themselves (and researchers) “cover stories”. These are stories “constructed when incommensurable gaps or conflicts between individually and socially constructed narratives emerge” (p.162). They further suggest there are compelling reasons for teachers to appear to be living the “socially authorized story or stories” (p.163), regardless of the fit with their own personal views. This comes at a cost:

Enormous stress is created when individual teachers attempt to live or tell stories given to them by others while simultaneously covering up, yet living, the story created through their own narrative authority. (p.177)

Olson and Craig say that when researchers shape and share cover stories through a highly selective retelling of aspects of the stories the teachers tell, they are contributing to the “restorying” of teachers’ experience, in ways that can transform the “vision of the whole” (p.165). This leads back to the ontological idea of the performativity of research in shaping “reality” rather than just describing it.

If we accept that research does ontological work in the world when it names and describes objects and events, we must also pay attention to the ontological politics of research because sociological questions are not only questions “about truth. They are also and at the same time, questions about what there should be in the world, about politics or ethics” (Law & Urry 2002, p.4). Law and Urry say that, if multiple realities are always produced, research should help to work towards making some versions of reality more “real” while eroding others. But how might such ontological politics play out? To address that question, the final part of this section returns to the ideas of the network theorists and of the pragmatists, whom I see as their philosophical “cousins”.
Constructing new “realities” for life in a pluriverse

More than a decade ago now, Lather (1991) asked “How do we frame meaning possibilities rather than close them in working with empirical data?” (p.113, emphasis in the original). I am interested in the multiple possible ways that science teachers’ realities can be framed, because these insights, in turn, could lead to ways to reframe the NOS questions we ask and attempt to address through curriculum change. The challenge of adopting a “depth” ontology in research (Clegg 2005) begins from the moment of question posing because, as Biesta and Burbules (2003) point out, for pragmatist researchers, the “problem” gains its greatest clarity at the moment of solution, not at the beginning of the research journey.

I have already dealt with the challenges posed by writing a tidy linear historicised account of a project that is shot through with messy, sometimes fortuitous actions and decisions but this insight adds a poignant new dimension. This is not just a matter of tidying up the research account after the fact. Rather it is to admit that my beginning intentions were, at best, sincere if misguided. More encouragingly, for the pragmatists, the consequences of actions are the important arbiter of “truth” (Biesta & Burbules 2003; Cherryholmes 1999). I see this position sitting in close alignment with the ideas of performativity and ontological politics of the network theorists. Accordingly, I need to address ways I have dealt ethically with my research responsibilities in this regard.

Taking up the theme of consequences in relation to educational research, Cleo Cherryholmes (1999) suggests that the risk of making a single framing of meaning can be avoided by adopting a “pragmatist reading” technique for analysis of empirical data. This involves taking one set of research findings and “reading” the claims made for them from the perspectives of different theoretical frameworks, thereby tracing all the conceivable practical consequences:

An extended pragmatist exercise in reading... seeks to clarify meanings with an eye towards consequences, even though meanings may turn out to be elusive. ... while facts about objects and events are one thing, what they mean is something else. Pragmatist readers emphatically reject the idea that facts or narrative plots or theories or metaphors or statistical explanations or formal models ever speak for themselves. They also reject the contention that texts have but one meaning. (Cherryholmes 1999, p.54)
Here are echoes of Cary’s concerns about the essentialist and humanist ways narrative can be unproblematically read (Cary 1999). But what Cherryholmes models is multiple theoretical framings of the same data, leading to different narrative accounts of the “reality” the data tell. While constraints on the length of a thesis curtail too enthusiastic an adoption of this recommendation, I have attempted to follow it by taking two quite different methodological approaches to the analysis that follows. In Section 5 I follow the ideas of the narrative theorists to construct three teachers’ (postmodern) stories of themselves as fellowship participants and as teachers. Then in Section 6 I carry out a more traditional structural analysis to describe the contexts in which the teachers carried out their work, through their eyes.

Throughout I have tried to remain alert to the challenges network theorists outline for social science research in the increasingly technological societies of this new century:

We have also argued that sociological methods are not particularly well adapted to global complexity. What worked well, and helped to enact, nineteenth century realities, works much less well at the beginning of the twenty-first century. Sociology has yet to develop its own set of methods for understanding—and helping to enact—twenty-first century realities. Current methods do not resonate with important reality enactments. They deal for instance poorly with the fleeting—that which is here today and gone tomorrow, only to re-appear again the day after tomorrow. They deal poorly with the distributed—that which is found here and there but not in-between—that which slips and slides between one place and another. They deal poorly with the multiple—that which takes different shapes in different places. And such methods have difficulty in dealing with the sensory—that which is subject to vision, sound, taste, smell; with the emotional—time-space compressed outbursts of anger, pain, rage, pleasure, desire, or spirituality; and the kinaesthetic—the pleasures and pains which follow the movement and displacements of people, objects, information and ideas. (Law & Urry 2002, p.9, emphasis in the original)

I am very interested in the challenges posed here although I make no particular claims of methodological innovation in my work. But if I have succeeded in drawing a convincing ontologically – focused account of how teachers come to produce “science” in the classroom in the ways that they do, I will have achieved the aim of answering the question that now presents itself.
5. Narrative and identity: doing science in research and in the classroom

Introduction

This section re-presents the stories three of my participants told themselves and me about their learning during and after the fellowship year. Following advice from the narrative methodology literature, I have not taken the stories as told at face value:

Rather than attempting to make unrealistic claims for representing ‘reality’, life historians should simply acknowledge what they are able to do with the stories they use as data: namely, offer an interpretation through their writing and spell out the influences that may have coloured both the teller’s story and their interpretation of it. (Goodson & Sikes 2001, p.48)

Wallace and Louden (2000) describe how they took account of “four sources of instability in the analysis of narratives” (p.6) when telling stories of science teachers’ learning. The first of these, the challenge of establishing “truth” when fact and fiction can no longer be seen as a binary, I have discussed in Sections 3 and 4. The second and third issues, authenticity and interpretation, are closely interrelated. Teachers should be able to recognise themselves in the narrative and I have addressed this by the use of direct quotes wherever possible. However the ordering and juxtaposition of these quotes, as well as the linking commentary, are my choices. I am the narrator but this does not mean mine is the only possible interpretation. I have tried to shape the stories in ways that remain open to reinterpretation and have invited my participants to respond to them in this spirit. Others are free to do so too. I address Wallace and Louden’s fourth issue, generalisation, in the final part of the section where I discuss the three stories in relation to the wider thesis question, and the growing literature on teacher identity.

This then, is my interpretation of the experiences recounted to me during four interviews across two years, the first year vivid with new learning in a science research setting, and the second marked by a return to teaching. I have ranged across all four interviews to select and re-present aspects of the conversations that concerned science being made, either in the research setting or in the classroom. I
examined the conversations for pointers to each person’s epistemological beliefs, as these were likely to be expressed, implicitly or explicitly, within a traditional humanist theoretical framework. I also sought out comments that reflected, usually implicitly, ontological aspects in the stories, using the ideas outlined in Section 3. Throughout the process I was alert to the prospect of finding narrative difficulties and cover stories, as outlined in Section 4. A quite different identity for each teacher became apparent as the analysis unfolded. I also used insights from research that links science education, NOS, and the identity of teachers or learners, to make some concluding comments.

Multilayered analyses are not told in a few words, especially when the intention is to keep as much original dialogue as possible in the flow of the unfolding story. For this reason, only three of my participants are introduced in this way. Choosing three was not easy. I could have constructed similar stories for any one of the eight teachers. I chose Bridie and Sarah because their stories seemed to incorporate some elements common in the women’s stories, one from a primary teacher’s perspective and one from a secondary teacher’s perspective. I chose Mark because his story had some different elements that provided a point of contrast to the other two.

After their initial shaping, I emailed the emergent stories to each of the three teachers, for their reactions and comment. Bridie did not respond, and indeed had intimated earlier that her participation had been completed. Mark responded briefly to say he thought the ideas had been drawn out well, and to ask if being compared to a cyborg was a good thing. Sarah did not respond until early in the new year, when she had had time to rest and recoup some energy. Hers was the longest response but she, too, thought the ideas had been well developed. She found the discussion had made her face up to some frustrations she had been reluctant to own, although it is hard to say if her decision to change schools had also empowered her to do this! Other comments she made will be inserted in the relevant places.

**Bridie’s story: Uncertainties and transitions**

Bridie is a primary school teacher who was “interested in science long before I applied [for the fellowship]” (Interview 1). She thought this interest came from “my father who is like what you’d call the original conservationist—an organic gardener
and things like that. He used to always point out things in the environment, and take us places—into the bush or to the beach’ (Interview 1). She had also been influenced by an early learning experience:

I remember a teacher I had at primary school who took us out to look at a silver birch tree. It was the first time I had looked in great detail, and I was absolutely amazed to see that there was all this here in this tree that had been outside the classroom probably for years and I hadn’t even noticed it. And so that is one experience that stands out. (Interview 2)

Despite this longstanding interest in science, Bridie thought she knew nothing about NOS. Asked what the title of the first curriculum strand—Making Sense of the Nature of Science in its Relationship to Technology—meant to her, she admitted:

I read it and I read it again, and I thought to myself, I have never ever looked at those words and wondered what they meant. And the more I looked at it the less I knew what it meant (we both laugh). . . . I must admit I have never really concentrated on that strand or decided that this is what I am doing, connected to that. I haven’t really thought of that strand as being very important. (Interview 3)

Bridie was surprised when the NOS ideas we had discussed were pointed out to her in the fourth interview. The subsequent analysis of all our conversations revealed that she had an interesting NOS philosophy that appeared to be poised at a moment of potential transition, even though neither she nor I was aware of this at the time.

**Bridle’s epistemological orientation**

Lederman and his colleagues (2002) found that those with “expert” NOS knowledge are far less likely than those who lack such knowledge to believe that “scientific knowledge is based solely on empirical evidence” (p.507). On this criterion, Bridie is what these science educators would call a “novice”. When challenged to differentiate science from other types of knowledge, she said “science knowledge isn’t just knowledge on its own. It has to be linked to the real world” (Interview 1). When discussing school science she said: “I think observations are more important [than experiments] . But I mean that is quite similar—you set up an experiment and then you look and see what happens” (Interview 2). When asked how her experiences of the science she was doing during the fellowship were similar to or different from what children do in school Bridie’s comments echoed her own powerful school learning experience of years before:
They both contain observations. I think observations are looking really closely at something. Much more closely than you would normally. They are both the same and that is the sort of thing I try to get children to do. (Interview 2)

Yet the second interview also showed that Bridie’s fellowship experiences had led her to the realisation that observation was not quite as straightforward as it might seem:

You know those questions you were asking before about knowledge. It’s—you can’t just say ‘Oh, I know’. You take a long time and a lot of different observations, different situations and talking to different people, reading different books, before you really get this—this whole picture. (Interview 2)

This insight into the effort needed to understand a situation from multiple empirical perspectives reinforced her belief that “your knowledge… is not necessarily what anyone else has gained. Your knowledge might not be the same as someone else’s knowledge” (Interview 2). Which in turn led to the argument that:

Scientific knowledge is simply an opinion. It is probably a better informed opinion than just general opinions. . . . Well the scientists have based it on lots of experiments and observations no doubt. But it is still just their opinion. (Interview 2)

Building on earlier research on stages of epistemological development, Thoermer and Sodian (2002) describe five levels of development of NOS views. Bridie seems to be in what they call a “transitional stage”—Level 3 in their typology. They describe this as a stage characterised by “a focus on either theory or interpretation, failing to integrate both aspects” (p.270, emphasis added). Bridie’s fellowship experiences led her into an epistemological struggle, heralding the potential for transition towards more nuanced NOS views. Her focus in the above comments was on interpretation, yet theory-building was there, lurking in the background, as a rich part of her fellowship experiences. Why did this seem to go unrecognised? The story continues with a missed opportunity.

**Learning and ontological change**

Although she would not have used the term herself, Bridie showed an interesting awareness of an ontological transformation in her own ability to carry out observations during the first half of her fellowship experience:
It is just amazing how—after a while you sort of realise, you know stuff—you will see something and you think ‘Oh yeah that is a [name of species]’ and ‘Oh yeah that is a [another species]’. And it is almost like you don’t know how you actually know, but it has just become part of your knowledge, has come part of you somehow. (Interview 2, emphasis added)

Her “look and see” epistemology, in combination with the idea of the potential for rich learning experiences to transform perspectives, seemed to reinforce her explanation of situations in which different scientists interpret evidence differently as “you just look at things in a different way. Different people look at what they see in a different way. What one person draws as a conclusion isn’t necessarily what someone else does. And they are both right, well in their way of thinking” (Interview 2). Bridie also found a way to resolve the relativistic dilemma of how only one of these different conclusions would actually be justified within current scientific understandings. In her view, an incorrect interpretation was a consequence of not taking a sufficiently broad perspective on the situation: “They may already have preconceived ideas and are only seeing what they want to see. And they are going down one particular track left and everything they see fits into that” (Interview 2).

Yet, when asked if she had seen this happen to any of the scientists with whom she had been working for the best part of a year, Bridie admitted she had not. She did feel that some “avid conservationists who want to save everything and keep people out of everywhere” (Interview 2) might fall into this trap.

Congruent with these views, when asked what the word “attitudes” meant in the curriculum strand entitled Developing Scientific Skills and Attitudes, Bridie said “I think it is just the way you look at science, whether you are open to your ideas or open—something to do with openness” (Interview 3). She could not recall any times when she had spoken about attitudes and values with the scientists with whom she was working. But it was “obvious” that certain attitudes did influence their work because they “are just so passionate about their work. They are just keen on conservation. It’s just there all the time” (Interview 3). She felt this passion would influence their work, although she had not personally seen any evidence of how that might have happened.

As with her ideas about observation, Bridie could confidently identify ways in which her own experiences of learning that became “part of you somehow” could potentially be used in the classroom when she returned to school:
The other thing is what I said before about taking your time to learn. About having to look at something from a lot of different views, in a lot of different ways, in different experiences before you internalise it all. And I think that is what I will really try to do at school with all subjects. ... Some subjects will be easier than others. I think this is a problem with our system where you have all your objectives and you have to tick them off. (Interview 2)

What seems to be missing here is an appreciation of the theory-laden nature of observation (see, for example, Millar & Driver 1987). Bridie’s explanations could integrate theory and interpretation if she knew how to relate the ontological changes she sensed in herself to a theoretically informed reorganisation of her ability to observe. Using bird-watching guides as an example, John Law and Michael Lynch (1990) use a metaphor of “reading and writing”, as opposed to a “perceptual” metaphor (p.293) to explore the subtle ways in which theory can be used to organise the observer’s gaze. From the perspective of this different metaphor, bird watching becomes “a moment in a hermeneutic reading of the world” (p.269). They demonstrate how a different “tacit ‘picture theory’ of representation” (p.273) underpins each of the three bird guides they analysed, with the various theories resting on different assumptions about how the tricky activity of bird watching in the field should be modelled.

Usefully, from the point of view of our story here, Law and Lynch go on to suggest that this type of analysis of a familiar, even mundane, activity “reflects more general processes of [scientific] apprenticeship in which textually ordered ‘knowledge’ is elaborated in the course of practical investigation” (1990, p.294). For Bridie, coming to appreciate the theory-laden nature of her own field observations could have provided a key to moving beyond her current transitional NOS understandings, towards a more integrated view of theory and observation. However, Law and Lynch also note that the theoretical dimension of the organisation of field guides is tacit, not explicit. The knowledge of more expert peers is, by contrast, overt. But they, too, may lack an understanding of the ways theory has shaped the observation and data gathering techniques they use.

In the absence of an informed guide, Bridie could not have been expected to understand her experiences in this way. As we shall see, her struggles had ongoing ramifications.
Learning experiences and narrative difficulties

Bridie’s research required her to develop observation protocols to document distribution, breeding activity, and so on, for a range of species residing in a habitat under stress from human activity. As early as the first interview Bridie showed an awareness that what seemed initially like straightforward observations could be more complicated:

At first I thought it was going to be quite simple [observation aspect of project]. It’s become a lot more complicated than that and I haven’t quite worked out yet just how to actually record things and then how to actually work out what the success rate is. (Interview 1)

She added that she was going to need to be more “scientific” and when asked what that was likely to entail she said:

Oh, a lot more note taking. And a lot of it is probably more statistics than science—they’re quite interlocked really. Just how you interpret what I’ve found [followed by a discussion of several contextual dilemmas that could be open to different methods of interpretation]. . . . Drawing conclusions is quite difficult I think. (Interview 1)

Later she faced the prospect of writing a scientific report of her work without really having “a proper idea of how to set it out and the proper scientific way of reporting everything” (Interview 2). Part of her difficulty with writing a clear report was the recognition that observational studies are complex and not restricted to one thing at a time:

I wasn’t just dealing with one small area. If I’d just reported on birds I could have put down my methods of how I studied it and my results. But because I was doing [names four broad groups of living things] (chuckles) it made it a bit sort of messy and I didn’t know whether to put all my methods first for all areas, or put my methods and my results and then conclusions for just the [group named], and then do the same for the [names another group] and (dissolves into laughter) I worked it all out in the end. I did all my methods first. And then all the results. And then the conclusions sort of all fitted in together. (Interview 2)

Notwithstanding this new awareness of the complexities and layers of decision making in constructing new science knowledge from observational studies, Bridie’s “look and see” philosophy was still an evident feature of our conversation at the end of the second year. Yet early the next year, looking back on her experiences, she worried that her inability to control all possible variables in the face of the need to sample in a complex real-world setting might have compromised her work:
I tried to do these observations over different times each day, so it wouldn’t be the same
time each day. But then because I did at this particular time of day, the four-wheel
motorbike went by. If I had done it half an hour earlier it wouldn’t have. I just felt that I
wasn’t getting a true picture in some ways, because of all these extra things. (Interview
3)

Here we see Bridie’s tacit awareness that the use of statistical procedures for
describing aspects of an eco-system was at best a compromised method for
describing “reality”. As the systems theorists would say “increasingly complicated
phenomena made for decreasingly reliable characterizations” when using linear,
Euclidean analytic tools (Davis & Sumara 2005, p.311). The seeming contradiction
between Bridie’s awareness of sampling and reporting complexities on the one hand,
and her continuing support for a “look and see” epistemology on the other, are
indicative of narrative difficulties (Chase 1995). Her personal stories of her
fellowship experiences could not meld seamlessly with her identity stories that
recalled instances of keen nature observations from a young age, so she held these
rather different versions of empirical science in unresolved juxtaposition.

When asked if her awareness of the uncertainties of sampling processes used during
observational field studies would influence the way she introduced simple “fair
testing” models to children, Bridie said it would not—at least for the level at which
she worked. Children needed to learn these simple models, but perhaps later they
could wrestle with the same issues she had just faced:

It is hard enough to teach them just what to do, without confusing them with ‘it can’t be
right because of this, this and this’. And maybe it’s not too important at first, probably
best that we just teach the children how to do a fair test, and worry a bit later. (Interview
3)

Bridie’s belief that children need to begin by learning simple things led her to draw a
line between her personal experiences of the complexities of observational studies
and the ways in which she could produce “scientific observation” as a classroom
activity. It may be that the widely held belief in children’s simple step-wise
development is acting here as a cover story (Olson & Craig 2005) to hold her
awareness that science is not really like that at bay. Or it may be that, in the absence
of opportunities for supported metacognitive reflection on her own learning, she has
not been able to find a way to reconcile her personal doubts with her more certain classroom practice.

**Sarah’s story: Fieldwork and history of science stories**

Sarah is a secondary school biology and science teacher who entered the teaching profession to combine her desire to help people with her passion for science in general, and biology and conservation in particular. Her delight in direct experiences of the natural world shone through all four conversations, as for example in this small encounter when working in the field on the conservation project that was her science fellowship:

> I looked down and there was a gorgeous little fluorescent beetle—okay I’m a bio teacher—and it was just wonderful, struggling to get across the path. And I came back and looked at my books, and it looks like it’s a Manuka beetle. But it looks better—what I saw was better than in the books. And, I mean, that’s knowledge. (Interview 1)

Like Bridie, Sarah did not see the relevance of the first strand of New Zealand’s curriculum—Making Sense of the Nature of Science in its Relationship to Technology. To her the meaning of the strand lay in the reference to science’s relationship to technology. Once a separate technology curriculum existed, teachers could “drop it quite happily. I mean it comes in to our area. Of course it does! But why waste your time on that when somebody else is teaching it?” (Interview 3). When prompted to drop off the “technology” reference she interpreted any residual meaning in the strand as “just working within science. And making sense of what science—whatever science you are doing—whether it’s chemistry or whatever” (Interview 3). When asked how that differed from what was intended by the curriculum’s “content” strands she reverted immediately to the emphasis on technology, saying that the NOS strand was put into the curriculum because “there was a political government push for technology. And we have to have people upskilled in technology. That’s been a governmental push for at least 10 years” (Interview 3).

In retrospect, Sarah might modify this view. She wanted me to know she has since taught a biotechnology topic in Year 13 biology that she particularly enjoyed and in her feedback she commented that she endorsed Mark’s views on the importance of technology to science. (These are outlined shortly.)
Sarah’s epistemological orientation

Despite her seeming inability to identify and articulate any NOS ideas in relation to the intentions of the curriculum, Sarah was deeply interested in the relationship between the social conditions in which new science knowledge is formed and the type of knowledge that results. In part this was because she had a keen interest in the history of science and read widely in this area. Darwin’s work was a particular passion. For example, when asked what place she saw for values in the science curriculum she mused:

Darwin struggled with the Christianity aspect of his life, with his theory—evolutionary theory—and his wife was very pro the whole Christian approach, and I presume she probably believed in Genesis and the way it worked as well. I mean Darwin was having to struggle with all of that. (Interview 2)

At the start of the second interview, before the first question had even been asked, she was keen to share her most recent reading about Darwin’s voyage to New Zealand:

I have been reading a lot about Darwin you see. I love Darwin and I was just fascinated the other day. I was reading a book that has been written by his grandson who is a qualified scientist and a Fellow of the Royal Society of England, retired. He has written [about] where Darwin has made observations. He has written about the actual scientific facts we now know about those organisms or situations he observed. I thought it was fascinating when he said Darwin was one of the first to look at the behaviour of animals in their situation, rather than just looking at the anatomical, grabbing the specimen and looking at skin colour and skin type and the anatomical bits. He was actually looking at the live animals and describing how they were behaving. And also he was one of the first—and Lamarck—he mentioned a couple of other scientists and Lamarck was one—where they looked at the ecology, how they related it to the environment and these were sort of forerunners of today’s ecology in a science approach. I thought that was all interesting. (Interview 2)

What Sarah has described here is an important paradigm shift (Kuhn 1962)—a new way of combining naturalists’ observations with the beginnings of ecological theory to arrive at the idea of adaptation, which so powerfully under evolutionary theory to this day. The whole idea of ongoing change in science understandings was something that kept her interest and passion alive:

I think science is never, never static. It is always changing. Well that is where I’m coming from and I say that to the students. The beauty of the subject is there is always more new material coming through and things we may think of in a certain context. I suppose genetic engineering is a big one there. (Interview 2)
Despite this emphasis, when asked if and how she would use the story of the shift in Darwin’s thinking in the classroom, her response hinted at a view of observation similar to Bridie’s—a view that missed the epistemologically sophisticated tenor of the story she had just told. Sarah thought students should learn from this story “the importance of what has been before and how people in some ways haven’t changed. We are all out there still looking and observing, many of us who have got the science bent” (Interview 2). Like Bridie, Sarah wanted her students to experience and value the intensity of scientific observation in natural settings, and this was far more important to her than any distanced consideration of abstract science philosophy.

Also like Bridie, Sarah felt that different theoretical interpretations of the same observations are a matter of what you see: “A Court of Law finds this when they have witnesses. … That just shows the observational skills that we have and how people interpret what they see is so different” (Interview 2). However she did see an important, albeit potentially flawed, role for scientific processes when trying to determine which interpretation was correct:

You have to try and get the facts and some credible, valid data. . . . I mean that goes back to the experimentation doesn’t it? If you are able to set valid experiments that will give you the data that will back up that argument. But then you have got to be careful that the experiment is valid and the way it has been set up is valid and it is not too biased. And of course then you go into another arena, where what may be bias for one person may not be for another. I mean I value experiments but I’m conscious of the fact they can be cooked to read a certain way. (Interview 2)

Here we see an interesting variation of the struggle that occurs in the transitional NOS phase when the act of interpretation and the role of theory in knowledge building are not yet integrated into a coherent personal framework (Thörrmer & Sodian 2002). Some teachers do rig experiments to make sure they work as intended (Nott & Wellington 1995). Sarah may be indicating her awareness of this possibility. She went on to say she knew of instances when graduate ecology students, facing timelines for their projects that were unrealistic in view of their relative lack of field experience, had rigged data to keep to the schedules required by the funding arrangements for the work. However, like Bridie, Sarah retains her commitment to the possibility of certain knowledge and a realist epistemology.

**Ontological changes and challenges**

There were similarities between Bridie and Sarah’s sense that their learning from their field experiences had been transformative:
I do find if I am on my own I can hear and sense things better and I can—the females are very hard to find sometimes—and I can almost sense now. I hear a slight call and I know one is near me and I have usually not been wrong. I’m walking, and I can think ‘Oh yeah that is a slight call, it is very soft.’… I can see the difference from the start of the year, that I actually can distinguish different birds with different calls. I would say that is the most exciting thing, and actually seeing the birds and how they are interacting. And the questions - the more you see, the less you seem to know. (Interview 2, emphasis added)

Sarah, too, recognised that this sort of highly intuitive knowing had not developed quickly, but was the result of sustained hard work and deep experience. “I think the time would be the factor. The amount of time it has taken to do the good observations” (Interview 2). This realisation lay behind her explanation of graduate students’ reasons for rigging field data.

Sarah was passionate about fieldwork and often made reference to the rigours it entailed. These were a recurring motif in the conversations and the harshness of the conditions in which certain types of knowledge are gained seemed to be a point of pride. For example, when talking about Darwin’s journey she commented that his crew had to “cope with some pretty horrendous travel conditions and it is amazing what has come out of that, especially those early voyages. But today you go down to Fiordland and you have got 20 dozen sandflies biting the hell out of you, while you are trying to observe a bird” (Interview 2). Later that same year, she recollected discussions with other scientists out in the field that canvassed “problems they’d strike and discussing how to avoid sandflies and that type of thing” (Interview 3). She made several references to having these sorts of conversations with students, telling them stories about the physical qualities needed to be a good scientist:

Some of those situations have been quite tough, in terms of the terrain you have to go through and swinging off ropes, and doing all those sorts of things. And that is what I will take into the classroom to the students. To be a good scientist and do the type of fieldwork that I am interested in, then you need all of those skills and it is a lot of fun. (Interview 2)

We were talking about water as a resource today. And I was telling them about a trek I did some time back in the Himalayas, and we didn’t have a decent wash for 13 days. And they were all horrified. And I said ‘Well we washed ourselves down each day but you didn’t have a shower.’ One of them said ‘But you have to have a shower!’ Well, not where we were! (she chuckles) (Interview 3)
In the retelling of rich fieldwork stories, Sarah had found she could have students “riveted quite quickly” (Interview 3). Ethnographic research into the practices of field ecologists (Bowen & Roth 2002) suggests such stories are a “common currency” (p.22 by which field ecologists build social cohesion as a research community. “Heroic” stories, in particular, are likely to be shared in informal settings, and are often allegorical in nature, helping other ecologists to learn vicariously from the experiences and (mis)fortunes of their peers. In this way, such stories are also used to enculturate fledgling ecologists, who are unlikely to have learned what they need to know to be successful in research in the field during their formal university studies. Sarah compared stories shared while out in the field with the banal nature of staff-room stories she heard immediately after she had returned to school (for example a colleague’s tale of finding shoes to wear to a wedding). Field stories were clearly important to her professional practice, both as an ecologist and as a teacher.

Paradoxically, the banality of staff-room stories may also serve an important ontological function. Olson and Craig (2005) suggest that “congeniality” is an important way for teachers to “smooth over differences and live together in complex, contradictory, tension-filled school landscapes” (pp.172-173). They implicate the need for smoothness, for the “still pond” with everyone in their place as an important driver of cover stories teachers tell when they find themselves at odds with official versions of the way things are in school.

Sarah also told other types of stories that built on her rich experiences of the fellowship year. When asked how her experiences might help her to help students learn, she said:

At the Wildlife International Conference, they had three really good models of these mustelids. And I asked if I could set them up on a table and take a good photo of the three of them—of the mouth-parts—with a view of using them in teaching, which is what I’m doing now. And, we were talking about what they can do. And I said ‘Well don’t replace your cat. Do things like that. And help track and kill some of these animals that are killing the native endemic birds, or animals like geckos, and stuff. ‘And I will take in a Fenn trap and show them. We won’t set it off. They are lethal things. And I’ll show them bait stations—how we set those up. And possum traps. I’ll show them those. So practical things that I’ve picked up I can take into the classroom now. (Interview 3)
Ogborn et al. (1996) describe science teachers as skilled “tellers of tales” that draw on a “multi-semiotic environment” (p. 139) where gesturing, drawing, showing visual material, and demonstrating with real objects can be variously pressed into service as the story unfolds. Sarah’s account vividly illustrates how her classroom stories would integrate her new learning with her existing motivation to help all her students develop a practical conservation ethic. Such stories introduce her students to science at work in real-world conservation projects, from an insider’s perspective. As in the case of her Darwin stories, the vividness of the “multi-semiotic environment” she has sought to create seems very at odds with NOS as a somewhat dry and abstract exploration of epistemological warrants for knowledge building.

Narrative difficulties, classroom realities, and cover stories

When asked how we get knowledge Sarah, like Bridie, emphasised the role of the senses: “I think our senses, which we tend to forget about. We’re too busy on the cognitive side” (Interview 1). Later in that same interview she said “We get knowledge in many, many, many different ways. It’s not just sitting in—I think sitting in a class, kids may learn one or two things in a lesson but by the end of five lessons they’ve had enough” (Interview 1). She had missed out on these sorts of sensory opportunities in her own learning:

I would have liked to have been taken in hand by somebody and taken out into the bush and sort of shown how to listen or what to listen for. You know, be given some skills and I was never given that. My science was limited in those days. It certainly was. University was disappointing. (Interview 2)

This theme of the vividness of lived experiences of the natural world and its scientific investigation is one I will return to in Section 6. However, notwithstanding her own feelings, Sarah said that providing rich field experiences for students “would be difficult. You have to have—teachers have to have their fingers on resources and people. And I certainly would not have had that if I hadn’t had this year out” (Interview 3). Despite her intentions to do more of this sort of work she realised that on her return to school she had “slipped into the same groove for some of the old habits, but that is survival” (Interview 4). When asked what these old habits were she said “running labs and students in terms of getting the material out to the students. Also teaching as well as you can, running the practicals, I haven’t changed too much in that way” (Interview 4). Sarah had been able to build on her fellowship contacts to
provide some fieldwork for some students. But these were exceptional rather than routine learning experiences. At least she was able to share rich stories of fieldwork, which it seems many teachers do not do (Bowen & Roth 2002).

There were narrative difficulties (Chase 1995) between the richness of the fieldwork, the fellowship stories, and some of Sarah’s pedagogical decisions. Like Bridie, there seemed to be a wall between some of Sarah’s own experiences of the complexities and embodied challenges of new knowledge building, and the simplified ways of knowing adopted when discussing her students’ learning. For example, in the classroom context, the skills of observation, for students, could boil down to something as simple as “well that is a small bird, that is a big bird, what do you think the difference is between the beaks?” (Interview 2). Similarly, Sarah’s interest in the ways social conditions impact on scientists’ work did not seem to translate readily to the classroom. Her conservation project had necessitated some delicate political negotiations but she said “I don’t discuss that with the students but I have discussed that with some groups I presented to like [name of group]. I told them about some of the issues that I had” (Interview 4). Sarah reasoned that it was not appropriate to discuss such matters with students because:

Now you don’t know who is sitting front of you with the classes. So I am a bit wary of giving that sort of information out. And also I am always a bit wary about talking myself in class. I mean you talk about your cat, various things but more on a personal level, don’t give too much out. I don’t think the students really respect that. You can’t be too familiar. Perhaps that’s what I’m trying to say. (Interview 4)

These reservations seemed to apply only to contemporary issues, where students’ parents could well be involved in local conservation efforts. Politically charged issues of the past were another matter:

The historical context helps you understand today, very much. I was saying to the students the other day that history teaches us such a lot and so much there we can use for understanding. Also biology, like we are talking about the potato blight. In those days they didn’t know what it was, but of course it was a fungus. We were talking about different types of fungi and what caused what. And I said well the potato blight in Ireland of course caused all the mass immigration from Ireland to Canada, here, Australia, the States and what a small bit of fungus can do in terms of causing a major upheaval of people. (Interview 4)

Clearly Sarah was very interested in science/society interactions and not afraid to discuss them if they were in the past. However her care and concern for her students’
emotional wellbeing (which was evidenced in many facets of the conversations) and her awareness of her teacher identity, resulted in self-censoring of the politics of work in her chosen area of science. Yet this was an integral and much discussed (with me) part of her fellowship experiences. The teller of such rich stories was silenced in one of the richest story-telling areas of all! It may be that simplicity, sensitivity, and manageability combine as aspects of a cover story for the “incommensurable gap” (Olson & Craig 2005, p. 162) between Sarah’s deeply held commitment to ecological research for restorative conservation projects and what she perceives it is possible for teachers to achieve in school.

In her feedback to me Sarah endorsed this interpretation of her beliefs but added another dimension. She noted that story telling “takes up time in class that is needed to wade through our very full science curriculums”. She had experienced situations where students saw stories as distractions from curriculum coverage and gave her negative feedback to that effect.

**Mark’s story: “Away we go” with science investigations**

Mark is a secondary science teacher with a postgraduate science degree and considerable experience of research. He commented that the science he was doing during the fellowship was similar to what he had done at university: “Once you got on to Masters you were doing your own research and stuff anyway. So, it’s a similar sort of thing, I guess” (Interview 2).

Quite late in the process of re-presenting Mark’s story I began to ponder his frequent use of the phrase “away we go” or “off we go” to signal plunging in to the next stage of a beginning or ongoing investigation, but not just as an isolated individual. Mark’s approach to his teaching was an all-action one, and he saw it as a collective activity, albeit with an individual taking overall responsibility for any one project. Unlike the other participants he had maintained an identity as a confident scientist. He enjoyed investigating and said that sharing this enjoyment was what had led him to become a science teacher:

> Oh I enjoy science. I find it fascinating. Because it’s got to happen ... [inaudible phrase] lots of problems to solve. And it’s everyday stuff I find for some of my students. Everyday. It’s really happening all the time. If you’re trying to look at cars and all that sort of stuff it’s like science. So there’s always more problems out there. (Interview 1)
He also felt that enjoyment, curiosity, and being the first to find something out were the main motivators of other scientists. “People just wonder and they—will this work or that work? And they enjoy doing that. … It certainly helps when you’ve got a project that no one knows answers to” (Interview 2).

Mark had published some science papers at different stages of his career, and clearly saw himself as a member of the community of scientists, although he wasn’t sure that his secondary school students necessarily saw him that way. He intended to use stories of his fellowship year to boost this aspect of his teaching authority in their eyes:

I’ve always been pretty keen on making sure they [students] are scientifically sound in their research methodology but it’s—having had that practical experience and being able to say “This is what I did at [name of fellowship host]” - they recognise that. Often students don’t see their teachers—their science teachers—as scientists. (Interview 3)

Mark had a reputation for successfully getting students involved in extracurricular investigations. He saw open-ended projects as “more interesting. They would be for me. If you get a kid’s interest—if you’ve got their interest in a project then you’re going to get a far better result out of them than something they’re not interested in” (Interview 3). He continued to draw on his experiences of a wide range of student projects over many years as an important source of his own learning about science.

**Mark’s epistemological orientation**

Doubtless because of his wide experience of different research projects over many years, Mark was well aware that empirical questions do not lead self-evidently to appropriate investigative strategies:

Well as soon as you get into biological systems, I’ve told kids that if it’s a biological problem it’s going to be fascinating because you probably won’t find the answer (laughs). You know, bacteria in soil. If people want to look at bacteria in soil, there’s so many in a cubic centimetre. … And they just suddenly realise that, once they get into it, they realise that, well the answers aren’t all cut and dried, and they start getting a bit hooked on it. And that’s the fascination of science. (Interview 1)

Mark recognised that methodological questions were best addressed by scientists with research experience in the area in question, both past and present, and he was not afraid to draw on the available pool of expertise whenever necessary:
When you teach research, one of the first things you say is that no one is a fountain of knowledge about everything. So a good researcher will use all the resources available, including the literature that has gone before you and then also people who have expertise in areas you might need it. ... So that’s how you get to tackle things. You just, you don’t worry about knowing everything as long as you’ve got a good argument for your design it’s not a problem. ... You’ve got to be able to put it together. But they’re pretty good at framing things up. Most scientists I’ve spoken to, and I speak to a lot with my kids’ projects, can really frame things up pretty well. So long as there’s the basic problem, it’s okay, and then they help out. So that’s how you get confidence through to your kids by saying, “Well I don’t know this. I can teach you that, but I can’t do that, so off we go to so-and-so.” (Interview 1)

He saw this as the sort of thing any reasonable person would do: “I haven’t got expertise in some of those areas. And it’s just like anything, if you don’t know it, you find somebody else who does” (Interview 4).

Asked what attitudes meant in the “scientific skills and attitudes” strand of the curriculum, he expressed a desire to see students also gain the confidence and dispositions to ground their own investigations in the collective experiences of a community of investigators:

The ‘scientific attitude’ is about being able to think about alternative ways around doing the problem—alternative approaches that might be better or worse. And having an overview—a good overview as well, I think is how you do attitudes. And a little bit of excitement in the way they are approaching the problem as well. (Interview 3)

Mark saw experiments as an important part of science because “you’ve got to have data to look at to generate your ideas from or to help develop some ideas” (Interview 2). Once existing data had been used to help design a new inquiry, another round of data would be subsequently generated. “So you design your trials and stuff so that you’re going to get accurate data from it . . . with a good design, you get good reliable information from it, and then you’re away” (Interview 2). In this way, Mark described an iterative and creative relationship between empirical data, question posing, and question answering. He also knew that there is more to investigating than just the use of reasoning skills:

Some people are very good at doing things in science. I’ve got some very good kids with skills like that and sometimes people have an innate ability to pick out the right course of action. And I guess that’s selection of procedures—which are ways to do things—that are an important part of that. Selecting the right way to go about doing something and showing something, and looking for things that are bucking the trend. Without that people like Fleming and co wouldn’t have got anywhere. (Interview 1)
As Mark saw it both the intuition/flair that he hints at here, and a sound theoretical knowledge, are important because “before you can go on and do marvellous musings you have to have some idea of the basics” (Interview 1). However, he was aware that “there are examples that people throw up of someone who knows without that schooling. Didn’t Albert Einstein get chucked out of the fourth form?” (Interview 1). In the second conversation we came back to this theme. On that occasion he identified “flair” as a difference between sciences and arts: “You can’t create music that people want to listen to without having someone who’s got a music flair. And when you’re talking flair, you’re talking art I suppose” (Interview 2). There is an interesting narrative tension here between the tacit recognition of investigative flair in the first interview and its explicit assignment to only the arts in the second.

In contrast to Bridie and Sarah, Mark appeared to hold what Claudia Thoermer and Beate Sodian (2002) call a Level 4 “beginning appreciation of a critical relativist stance” (p.270). He was aware of the role of theoretical frameworks in the interpretation of evidence, which is Thoermer and Sodian’s criterion for “Level 4”. However he did not draw on this understanding when asked how scientists could come to different conclusions about the origins of the universe when they are looking at the same data. For him this was still a question of data rather than theory: “Because you haven’t got any way to measure these things. So, half of it is educated guesses” (Interview 2). His earlier comments about students being scientific when they tinkered with their cars also suggests he still has a leaning towards a simple empirical realism, at least with respect to his students’ informal science activities. For reasons I outlined in Section 3, I am not so sure that teachers’ awareness of the role of theory does signal a developmental move towards a more relativist philosophy. Nor am I convinced that this would be a safe position for teachers to adopt, and this is a topic I return to in Section 7.

Ontology, with the prospect of networks and cyborgs?

Alone of the eight participants, Mark clearly identified research as the source of new knowledge:

It’s the job of universities to advance knowledge. ... Doing research advances knowledge. So that’s what you are doing. Trying to build up basic knowledge, you’re contributing your little project anyway. It’s big to you, but in the scheme of things it’s adding to the pool of knowledge that’s been built up over the years. (Interview 1)
Like Sarah, he also made strong links between science and technology. However, rather than seeing this aspect of NOS as something that could be left for others to teach, science at work in the world was something he saw as an important aspect of science learning:

With your technology and your nature of science (pause) . . . How science impacts on us is where that comes from I think. Trying to think of science as more than just a lab, doing things and the applications. Whether it’s just producing a bottle of cream or something to rub on your legs or some sunscreen or something like that. It’s the common applications of things. In other words how wide is science? And do kids think that basically everything they do is science? So whether you’re sitting on a rowing machine or a wind-surfer, or in a pharmacy—it’s all science. And basically the clothes they are wearing—I tell them to read the label and ‘90% polyester’. Where does that come from? The rest of it comes from plants that are managed as well. So if they can see that—that nature of science—and then of course you roll your technology in. You know your applied science and all that. Then you’ve got a whole—a full spectrum for them haven’t you? (Interview 3)

There is an apparent conflation here of the processes of scientific inquiry and daily interaction with the technological products of science. I should have asked Mark how he saw these interactions as “doing” science, if that is indeed what he meant. Given that he had such a clear understanding of what investigations actually entailed, I suspect what motivated this comment (and the earlier one about cars) was a desire to see students take more notice of the benefits that science has achieved. Certainly, Mark understood “attitudes” to include this promotional aspect:

And then I guess you’ve got your overall attitudes towards science in general. Whether you’ve got a positive way of thinking about the contribution the scientists make to things. A lot of students think about science in a negative way. They think scientists blow people up and shoot people in wars you know. They don’t think about the fact that most of them would be dead if it wasn’t for people like Fleming and those sorts of people. How many people have never had antibiotics in their life? (Interview 3)

Like Sarah, Mark has a strong interest in science/society interactions, albeit expressed rather differently. I suspect this interest could be easily fanned by the ideas of the network theorists to include a strongly ontological perspective, if Mark was introduced to this possibility. Nor would the idea of scientist as cyborg seem to be much of a jump. Anticipating his fellowship learning at the start of the year Mark said:

Well I’ll have a better understanding of how the modern gear works. Mostly it’s just imitating what I used to have with a computer more or less. ... You can get your data
done so quickly. You can get so many things done, working right through samples. I just left them going overnight. It’s done by machine whereas before you had to do it all by hand. [you’re restricted in how much you can get. So I’ve collected that much more data that I can manipulate around and see if there’s any trends and things like that. (Interview 1)

We came back to this theme in the second interview: “The old spreadsheet’s quite handy because you can sort by whatever you like” (Interview 2) and again in the third:

It was quite interesting to learn all that new technology and working through to find out the results and get a standard curve and all that stuff. The basic underlying part is the same but it is different in how you use the computer program and I guess it’s just working through those issues. (Interview 3)

Mark has faith in the “black-boxed” aspects of science investigations done by analytic machines. In some instances it is evident that he can trace the work they do back to techniques he once carried out laboriously by hand. But in other instances he relied on the expertise of “these older statisticians who were really quite good in some of these projects” whereas “I just use it as a tool to find out if the data’s good or not” (Interview 3).

**Producing science in the classroom context**

Working in science and working in teaching were very different in Mark’s view. He commented on the luxury of having “the time to sit down and actually think” (Interview 1) during the fellowship. Later he commented wistfully on the collegial aspects of science:

The environment’s quite different for a start. You’re working with adults all the time so you can go and talk to someone about something pretty quickly, or you don’t know something you go and talk to someone about it. ‘Cos in teaching, you sort of, teaching in a lot of ways, is quite lonely. (Interview 2)

Once back at school he said he had been able to “use some of the work I was doing, in a simplified way. Some of things we were doing with our testing programmes are the sort of things they [students] can do with their projects. Things like fair testing. And doing trials. And having controls for trials and things like that” (Interview 3). This “fair testing” comment is interesting in the light of NOS critiques of this approach. While it was not an applicable method in either Bridie or Sarah’s projects, what Mark was doing could be seen as a more sophisticated version of controlled
experiments that might be carried out in school contexts. However, Mark was also clear that much school practical work is not investigative in this sense. He made a distinction between “experiments” that are demonstrations and those that are genuinely for knowledge building:

You try to teach content by experiments. But if you stop and think ‘they’ll combine and give off energy and a great cloud of smoke and flame’, that’s different from trying to find a concentration of some unknown hydrochloric acid or how much vinegar, how much acetic acid is in vinegar, or how much vitamin C is in fruit juice. Those are the different sorts of experiments. They’ve got different outcomes and you’re trying to backup your course and teach your course through the content that they can see and understand how these things do react quite strongly together and then you look at your electron diagrams and say why it happened. If you’re trying to find something else like how much Vitamin C is in fruit juice that’s been stored in a clear bottle for three months, as opposed to some that’s been put in the fridge, then that’s a different type of experiment you’re trying to do. You’ve got different outcomes there. (Interview 2)

Like both Bridie and Sarah, Mark spoke of keeping ideas for younger students deceptively simple. He made sure students were aware he had done this deliberately, at least as they got older:

The kids find this hard but if you’re up front with them, they seem to cope with it all right. If you’ve had them for a while, and you take them through, then they will say ‘This was just another little bit of fudging in the earlier days wasn’t it?’ And I will say ‘Yes it was. But I didn’t want to give you a brain haemorrhage then.’ They’re happy with that. They’re happy to change it because they know you explain to them, ‘Well, I didn’t want to give you too much grief in the third form so we just simplified it for you.’ (Interview 2)

Mark expressed a preference for students to do the more open investigations he enjoyed doing himself. But he said he would only do so “if I’ve got a good group of kids. I like doing that. I’d rather do that than give them a recipe and just churn through it. I know you have to do quite a bit of recipe stuff” (Interview 1). When I asked him why he felt he had to do recipe practicals he added:

Because you haven’t got the resources. There’s too many kids in the class. But when you’ve got a good class you can subdivide them and get some working differently from others. Or sometimes get a project with two or three variables. And one lot can try and use one, and one lot with another, and that’s how I go about teaching that. And with a good class it works well. (Interview 1)

A good class would be one with “bright “students who are well behaved, interested, and easy to control. Expressing similar views to Bridie and Sarah, he felt other students would experience more success with more structured investigations. What
these students lacked was “natural ability, to help them think around problems and stuff like that . . . that’s what you need in these good top students . . . gotta have both the will power and horse power” (Interview 4).

There was a similar selectivity about the use of computers in the classroom, notwithstanding Mark’s enthusiasm for their use in his own investigations. He said he used them “where I can. But you know what it’s like in the classroom. You’re struggling to get the room, but I do set a lot of stuff up and use computers where I can” (Interview 1). Like Sarah, Mark cites practical constraints that prevent him from more routinely doing with students in class the things he values for himself as an active participant in science. There are indeed very real constraints to teachers’ autonomy in the classroom. Nevertheless there is a well-rehearsed feel to these accounts of constraints. Could they be deeply entrenched cover stories for the tensions created by the demands of mass schooling?

**Teachers are more than their practice**

In re-presenting these three teacher stories I wanted to better understand ontological as well as epistemological influences on each teacher’s production of “science”, both in their fellowship work and in their teaching. What emerged were rather predictable epistemological similarities (as determined by Thoermer and Sodian’s (2002) developmental scale) and more interesting ontological differences, Here are Sarah and Bridie as avid conservationists whose own fellowship learning experiences have forever changed them as skilled observers of the natural world. But there are differences in the way they see themselves, too. Bridie is a keen naturalist and careful observer of things as they are. Sarah is an adventurous ecologist, braving physical discomforts to help build new knowledge in the company of like-minded scientists. Mark, too, is a keen investigator, with a passion for finding new ways to answer challenging questions.

These stories then, are about identity, the “is-ness”, of each of these three people in their personal relationship with science. As Helms (1998) observed “teachers are more than their practice” and “there is much to be learned from the particulars” of their experiences, values, and beliefs (p.832). She describes four aspects of teachers’ professional identity as science teachers. Her study of five secondary science
teachers’ personal stories found a strong link between a teacher’s values and beliefs and their imagined future self, with a weaker link between values and beliefs and future actions. The fourth aspect, others’ expectations, linked directly to actions, overriding in some instances the teacher’s central values and beliefs. These observations ring very true for my participants, and they are not good news. Both Bridie and Sarah hope to leave teaching as soon as they can manage the transition, notwithstanding their continuing commitment to students’ learning that opens their eyes to the natural world. Mark, too, has expressed reservations about the teaching conditions to which he returned. How do these teachers manage others’ expectations yet remain true to their view of themselves in relation to science?

The wall as a metaphor for managing sub-identities

A recent review of the growing body of research on identity as a teacher (Beijaard, Meijer & Verloop 2004) locates current discussion in the field within sociocultural and postmodern theoretical frames. Here identity is not seen as a fixed “essence” but as an ongoing process of becoming oneself in relation to various contexts, which in this case include teaching. This results in the ongoing formation and maintenance of sub-identities that “more or less harmonize” (p.122) but may also conflict. The stories in this section have identified the potential for conflict in relation to all three teachers’ sense of science in their personal and professional lives. Yet they seem to have devised “stories to live by” (Connelley & Clandinin 1999) that help them manage this conflict.

Olson and Craig (2005) adopt Carol Gilligan’s metaphor of the cover story as “a wall” (p. 164) that helps a person to separate conflicting versions of events when narrative difficulties arise. There is reference to a similar metaphor in “Cleo’s story” (Munro 1998) where, for Cleo, the wall symbolises social constraints and restrictions. I find this a compelling metaphor. My interpretation of Margaret Atwood’s use of the wall in her most recent science fiction (Atwood 2003), is that it symbolises the separation of those who still have faith in science, progress, and order from those who live in the unruly, uncertain chaos of postmodernity.

Bridie, Sarah, and Mark, in their own ways, all seemed to build a wall between the richness of their fellowship experiences and their classroom practice. The fellowships provided satisfying instances of working through and overcoming
uncertainties about methods and about report writing. Awareness of embodied aspects of coming to know was a feature of both Bridie and Sarah’s learning. Sarah had successfully managed political aspects of her project and found this both interesting and satisfying. Yet these were not the sorts of stories they wanted to take back to their classes. On the contrary, these were stories for adults, or to be kept out of sight altogether. The bricks in the wall between their personal learning and their students’ learning included “keeping it simple”, by being the “expert translator”, while “managing the constraints”, and “keeping order”. All of these, along with the separation of “bright” students for learning that relaxed some of these conditions, interacted to keep uncertainty and complexity well out of view in the science produced in the classroom, even though it was very present in their own learning experiences. The result, as other commentators have pointed out, is that learning about science bears little relationship to the reality of actually doing science (see, for example, Chinn & Malhotra 2002).

Other researchers describe similar findings. One recent study compared three beginning teachers’ experiences of a science research project during a summer fellowship with the ways they subsequently produced science in their classrooms (Varelas, House & Wenzel 2005). These researchers used Gee’s typology of four aspects of professional identity: N or nature perspective (the personal identity of the individual); I or institutional perspective (the components of identity imposed by the organisational features of the setting); D or discourse perspective (features of identity adopted via discourses that operate in the setting); and A or affinity perspective (allegiance to certain other people and groups in the setting) (Gee, 2001). They found that discourse and institutional aspects of identity were particularly strong in both the research and teaching settings. But they were also very different in those contrasting settings. Comparing the fellowship to the classroom, contrasts they identified include: freedom in research/control in the classroom; lots of time in research/limited time in the classroom; messy research processes/linear orderly teaching processes; floundering in research complexities/basic knowledge and understanding needed first; taking risks in research/responsible for students in teaching; exploring in research/fear of not knowing in the classroom; and a theory-data dialectic in research/data emphasis in the classroom (Varelas et al. 2005, p.512). Facing these differences, the beginning teachers were “immersed in contradictions” (p.513) that pushed them closer to representing science as settled knowledge and away from
revealing its uncertainties and complexities, as they had experienced these during the fellowship.

While these differences may be particularly sharp for beginning teachers, my participants were once in that position too. It may be that this is a moment in time when the building of a wall between personal science and classroom science can be interrupted. Obviously this is a speculative question and would need further research. Once such a wall is tacitly in place, its metaphoric demolition must represent a considerable challenge. Jay Lemke (2003) points out that there is a temporal dimension to identity negotiation. Some aspects are well established and enduring. Other aspects may not last much beyond the context that triggers them. Maria Varelas and her colleagues found that their beginning teachers had N (nature) identities that were easily overshadowed by the other dimensions. But my teachers expressed very strong and interesting N identities during and after the fellowship, even as they had to leave them outside the classroom door to some extent. For them, the deeply entrenched professional sub-identity responding to the institution of school easily overrode the potential for the “science” they produced with students to be more representative of the actual experiences they so enjoyed.

Can the wall be dismantled?
Can time spent in working science be realistically expected to contribute to changes in NOS teaching at all? One suggestion is that learning experiences such as fellowships should sit alongside classroom teaching rather than be separated in time (Varelas et al. 2005). While this might help beginning teachers it would run counter to the “sabbatical” nature of fellowships for long-serving teachers. Another possible approach is to create a reflective space that helps teachers step away from the rich context of their own science learning to look back on it from the outside (Schwartz, R., Lederman & Crawford 2004). But these researchers also ask “How easy is it to shift perspectives back to the outside once one has become a functioning member of a community?” (p.638). They suggest that a strong sense of self will help promote such reflection. I see this as more hopeful advice. The “self” every one of my participants revealed during our interviews was interesting, dynamic, and unique. Opportunities for teacher fellows to carry out narrative analyses of their own stories, with appropriate researcher support, could help them identify and overcome barriers
to the production of NOS in the classroom that better matches their own rich experiences.

Another interesting possibility comes from a study of teachers’ worldviews with respect to nature (Cobern & Loving 2000). They locate views about science and nature within a “vast network of interrelated concepts reaching beyond science” (p.2) into other areas of teachers’ lives. This idea creates an interesting resonance with the ontological focus of the network theorists—for example their use of rhizomes as a metaphor for knowledge at work in the world—as outlined in Section 3. I will come back to this idea in Section 7.

There will, of course, be no single strategy that could work for all science teachers. It is quite obvious from the analysis here that these three teachers are very different individuals. I find it thought provoking that Mark, whose science project most closely conformed to the simple “fair testing” model of school science practical work, also expressed views closest to those who advocate for epistemologically-focused NOS teaching in schools. For Bridie and Sarah science was a more sensual, more uncertain process, grounded in the complexities of learning just how to make real-world observations in ways that were more “scientific”. Might not an ontological approach to NOS hold more intuitive appeal for them? The other five participants, whose full stories there is not space to tell, were also doing biological projects during their fellowship year. In Section 6 I use their experiences to further explore the question of a role for ontology in introducing a NOS component to the school science curriculum.
6. On “being” a science teacher

I know the easy approach would be just to do everything as I always have. Well I can’t do that. I can’t and be true to myself. Not after having learnt what I’ve learnt about myself and learning, and what I want for the students. . . . It is frustrating though. It is frustrating always wanting to make things better isn’t it? Because it means more work and it sometimes can be unpredictable in the way—in the path it takes. (Zoe, Interview 3)

Introduction

Section 3 drew attention to two different meanings for “ontology” in modern philosophy. In the traditional sense, it is about “being”, as opposed to “knowing” (i.e. epistemology). However, as the philosopher Stephen White (2000) recently observed, the “ontological turn” during the last century “came to refer increasingly to the question of what entities are presupposed by our scientific theories” (p.3). This somewhat different sense of the term “seems to have been increasingly appropriated in recent years in the social sciences” (p.3). It is in this sense that some science educators have spoken of, for example, an “ontological zoo” of entities that teachers must make real for students (Ogborn et al. 1996). This sense was also the main focus of Section 3.

Now, however, I want to return to that other sense—to consider my teachers “being” as people whose “ontological commitments . . . are . . . entangled with questions of identity and history, with how we articulate the meaning of our lives, both individually and collectively” (White, S. 2000, p.4). Just how might these two meanings intersect in the context of the NOS question? This is an unresolved aspect of the thesis I must now address. Posing the question in this way challenges me to locate the discussion about teaching in a theoretical frame that can take account of both the person and the wider context in which their work is located, without necessarily seeing the one as outside and separate from the other.

Responding to this challenge, I intend to explore what a non-dualistic ontology might have to offer the NOS question in the enacted teaching moment. To meet this new challenge, I shift my theoretical/philosophical lens from narrative theory/intersubjectivity to pragmatism/interobjectivity. In a pragmatic framing the measure
of which “truth” to adopt resides in the consequences that follow (Biesta & Burbules 2003; Davis 2004). Following Cherryholmes (1999) I attempt to interpret some of the reported teacher comments from more than one theoretical perspective.

Davis (2004) describes enactivism as an educational theory of knowledge and knowing with an interobjectivity orientation. The latter entails discourses in which “knowing is equated with being and thought is understood in terms of ongoing adaptations to dynamic circumstances” (p.110). When applied to the classroom via enactivist theory the teacher is seen as an autonomous individual but at the same time is “coupled to other agents, and hence, part of a grander form” where both internal and external aspects of thought are part of their “ongoing adaptive actions” (p.153). Here, then, is a theoretical orientation with the potential to integrate being and reality, explicitly as they apply in teaching, where interactions with others are at the very heart of a teacher’s work.

Two theory fields are subsumed under the umbrella of interobjectivity: complexity science and deep ecology. Davis (2004) locates the key difference between these two as inhering in the question of meaning. Whereas complexity sciences tend to follow the analytical, metaphysical sciences in explaining the world in terms of practical know-how, deep ecology is “more oriented to questions of meaning, ethical action, spiritual entanglement and mindful participation in the evolution of the cosmos” (p.1 61). Davis describes enactivist theories as entailing a simultaneous focus on knowing, being, and doing in the act of teaching, and he says these are inseparable. Within this theoretical frame, ethical action is a “mode of ongoing coping—a responsiveness to what is appropriate here and now” (p.176).

Davis is a mathematics educator. I find it very interesting that his discussion of the nature of being resonates with that of White, a political and ethical philosopher whose theory of “weak ontology” informed the way I have interpreted my participants’ comments that are discussed in this section. In doing so I make space for the voices of the five teacher fellows from whom we have not yet heard. I chose Zoe’s voice as a starting point because the comment above succinctly captures something of the passion and frustration that the teacher fellows expressed for their work, as well as an element of uncertainty. Zoe’s thoughts serve to underscore ethical dimensions to teachers’ being—dimensions that I am challenged to highlight
by the enactivist theoretical frame I have so briefly sketched in this introduction. Science teaching isn’t just about the science *per se*, let alone about NOS.

**The idea of a “weak” ontology**

White (2000) proposes a distinction between “weak” and “strong” ontologies as a means of resolving certain tensions raised by critiques of Western modernity. He describes “strong” ontologies as those that refer ethical and political questions to an *external authority* source that is unchanging, universal, and carries underlying assumptions of certainty (pp.6—7). Knowledge building within such ontologies is an activity of the “Teflon subject”—an “assertive, disengaged self who generates distance from its background (tradition, embodiment) and foreground (external nature, other subjects) in the name of an accelerating mastery of them” (p.7). Clearly, traditional views of the authority of Western science, as developed in conventional NOS epistemologies, especially when associated with realist ontologies, fit this view. So do traditional religions.

In place of this strong ontological position, White proposes a different way to anchor moral and political values and actions, without the need for recourse to a certain, external authority. He discusses a recent turn to “weak” ontology across a number of different research fields, including feminism, theology, postmodernism, post-Marxism, communitarianism, and some variants of liberalism. “Weak” here is by no means a pejorative term, but rather signals “acceptance of the idea that all fundamental conceptualizations of self, other and the world are contestable” (2006, p.8). It also acknowledges that such conceptualisations must nevertheless form a cornerstone of a reflective, ethical life. Within a weak ontology, subjects are seen as “stickier” and the *aesthetic-affective* must be taken into account alongside the cognitive. A commitment to such an ontology requires a thoughtful and regularly tended sensibility about what it means to be human, which White sees as necessitating “the measured pursuit of an array of related practices and self disciplines” (p.11). Thus this is not a laissez-faire relativism, but rather a disciplined, reflective, self-conscious articulation of the situated contingencies of knowledge and “truth” building.
These ideas resonate in interesting ways with Davis’ analysis of the commonalities of intersubjectivity and interobjectivity (Davis 2004). He sees both types of theoretical orientation as grounded in the natural world, or “physics”, as opposed to an ideal or transcendent world of “metaphysics”, which is where he locates rationalism and empiricism, along with gnosticism and religion. Davis also says that accusations of relativism misrepresent what is intended by intersubjective theoretical orientations such as postmodemism. And speaking of the challenges of employing enactivist approaches to teaching, he reiterates that this cannot be seen as condoning “anything goes” approaches, unpredictability and complexity notwithstanding. Indeed, if meaningful learning is to co-emerge in the classroom setting, he speaks of the importance of “liberating constraints” which are:

guidelines and limitations for activity that are intended to provide enough organisation to orient students’ actions while allowing sufficient openness for expression of the varieties of experience, ability, and interest represented in any social grouping. (Davis 2004, p.169)

I find this line of thinking helpful because it firmly retains both the ethical responsibility and the cognitive complexity of teaching, whilst nevertheless shifting the focus of the role from being the authoritative source of certain and settled knowledge. Given teachers’ likely subconscious concerns about relativism, as discussed in Section 3, any rethinking of approaches to NOS must be able to robustly defend itself against accusations of an “anything goes” lack of intellectual discipline, and to do so on terms to which teachers can relate.10

In another resonance, there are interesting similarities between White’s proposal of the concept of weak ontology and what others have described as a means of coping with the “supercomplexity” of late modernism. For example, Ronald Barnett (2004) argues that we should aim to educate students who will know how to “be” in a world where supercomplexity and open ontologies are the order of the day. Echoing White (2000) he defines supercomplexity as a condition in which it is impossible to find one certain consensus on knowledge debates—even hypothetically. Rather, Barnett

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10 In Section 7 I cite critical remarks, from a right wing political commentator, on the inability of New Zealand’s current science curriculum to deal robustly with the “intelligent design” threat to the teaching of evolution. Those remarks illustrate a type of “anything goes” misunderstanding of attempts to move beyond strong ontological positions. I suspect such misunderstanding has been widespread in New Zealand since the (sometimes overzealous) promotion of a constructivist approach to the present national science curriculum, mandated in 1993.
says, we need to learn to live in an uncertain world where the more we come to
know, the more profoundly we also recognise our ignorance. In this view, there will
always be “epistemological gaps” (p.251) that no amount of new learning can
anticipate or satisfactorily fill. The ontological challenge for each individual, he says,
is to find ways of being that do not render them unable to live fulfilling lives in the
face of so much uncertainty and choice.

**Implications for teaching**

In his discussion of the challenges of teaching and learning for an unknown future,
Barnett (2004) points out that questions such as “What is a teacher?” can never be
settled because, in principle they yield a:

> multiplication of answers and further questions. And some of those answers and further
questions spring from value positions and even ideologies that are mutually incompatible;
and there is no straightforward way of resolving these differences. (p.249)

This, he says, is the essence of the supercomplexity with which we must now live,
and to cope each person needs to find ways to live with ontological uncertainty while
garnering a sufficient “investment in their own selves that enables them to go forth in
a challenging world” (p.253). Like Barnett, Davis sees ethical participation as the
solution to the dilemma of knowing how to “be” in a complex world (Davis 2004).
He envisages a participatory epistemology that is “an ever-unfolding choreography
of action within the universe. In other words, knowledge isn’t out there. What we
know is acted out in what we do, and what we do contributes to the unfolding of the
cosmos” (p.101).

The difficulty with these types of comments is that they do not apparently point to
particular courses of action. How are science teachers to make sense of the already-
evident pressures of supercomplexity, inculcated as most seem to be in the strong
ontological positions of traditional Western science outlined in Section 3? White
(2000) says the ongoing task of building and maintaining a weak ontology
necessitates “a horizontal circuit of reflection, affect and argumentation” (p.11). He
proposes a three-cornered circuit, with two-way interaction between all points. These
three corners are (1) specific contexts of action, with their associated norms and
judgements, (2) ontological concepts, and (3) “one’s broadest historical ‘we’ claims
and narratives” (p.12).
As outlined in Section 2, discussions about NOS in the curriculum have been traditionally largely limited to epistemology, with implicit links to strong ontological positions. If teachers are to be supported to make changes that take account of more “participatory epistemologies” (Davis 2004) with their associated “weak ontologies” (White 2000) they are going to need rich opportunities to explore their teaching from non-dualistic perspectives. It seems to me that each of White’s corners of reflection has important insights to bring to bear on the question I posed at the beginning of this section: In what ways do the twin “reality” and “being” meanings for ontology come together in the context of the NOS question? Do teachers’ subconscious experiences of science and of teaching contribute to a tacit ontological “circuit of reflection, affect and argument” that currently creates invisible barriers to the implementation of a richer NOS in the classroom? Might a reframed “weaker” ontology make space for acknowledging the uncertain yet invigorating experiences described by Sarah, Bridie, and Mark, as outlined in Section 5, giving them “permission” to introduce these to their teaching practice?

Exploring this possibility, I have added to my intention to shape classroom activities that could provide a more explicitly ontological approach to NOS (which I still carry out as planned in Section 7). In this section I now extend my original focus to interrogate the potential of different entry points for helping teachers more consciously articulate their personal ontologies. If science education researchers can clarify the nature of the challenges entailed in building weak ontologies, maybe they can more effectively support science teachers to do the same, and thence to change their practice with respect to the ways they address NOS in their teaching. To explore this suggestion further, I discuss selected experiences and issues that arose in my interviews with Ross, Halifax, Lesley, Zoe, and Alice.

My beginning point is the broad historical “we” claims of my participants. This seemed a rich context in which to tell something of the five remaining participants’ fellowship stories. Here I discuss their “investment in themselves” (Barnett 2004) in their roles as people who are interested in science first, and who are science teachers second. The ontological focus is firmly on “being”, introducing ideas and experiences that, at least tacitly, powerfully inform their daily classroom practice. The discussion then directs attention to the embodied nature of knowledge teachers.
might draw on as they work. This leads me to explore ways teachers’ NOS decision making might be impacted by affective influences of which they are not consciously aware. The comments reported here suggest that very powerful feelings are invoked at the intersection of identity as a teacher and actual classroom work. This leads me to argue that NOS initiatives will be more likely to succeed if they work with, rather than against, these feelings.

**Teachers’ identity narratives: commitments to science**

I began my analysis for this section by collating all five participants’ comments that gave some insight into how they saw themselves in relation to science and to teaching. The sometimes ambivalent and contradictory responses, made across the course of the four interviews, and especially those made by the females, initially surprised me. Here are stories of an early interest in science, often squashed by their own formal science learning experiences, which in some cases were default choices. Notwithstanding this seemingly unpromising start, these teachers persevered in developing a passion for helping others to learn science, even if teaching itself was also a default choice.

**An early interest in science**

In Section 5 we saw that Bridie’s father fostered her interest in the natural world at an early age. Sarah, too, said she was keen on the natural world from a very young age. Two of the other teacher fellows also spoke of the impact their fathers had on their early orientation to science:

Well I went to university. I knew I wanted to major in science and my Dad was an entomologist. Those sorts of things had interested me and I did well in science in high school. (Lesley, Interview 1)

I was fortunate that I had, particularly, a father who encouraged my curiosity and interest. (Lesley, Interview 3)

My family were farmers and my father was quite interested in breeding. In the shearing shed he did the wool classing. I suppose I was 10 and I learnt how to classify or class wool. And I knew why to class them like that and I knew how you got that wool. What breeds, and what ram you needed to put with what ewe, to make that sort of wool. That was interesting, that was our livelihood. (Alice, Interview 2)
This suggests that aspects of these teachers’ rich experiences of the natural world, and sometimes of science, through their family backgrounds, “stuck” to become an integral component of their identity narratives as science teachers. The influence of family on school girls’ choice of science has been reported before (see, for example, Baker & Leary 1995). It seems likely that the types of science experiences that make their mark on girls may be different from those that attract boys to the sciences (Jones, Howe & Rua 2000). The latter reported girls’ greater interest in the natural world and aesthetics, and that they attached more importance to relational or “connected” knowing than did the boys in their research. Again, these insights are not really new, but what interests me is that these influences apparently continue throughout a working life.

Some default choices at university
Notwithstanding their early interest, both Lesley and Alice described a certain amount of default thinking in their choices of university study:

I went to an assembly of all the prospective science students at my university and then they started calling people up to meet with their advisers by disciplines. And if I tell you I majored in zoology you’ll understand how undecided I was (laughing as she says this). Because they took out the botanists and they took out the chemists and all you got left in the end was the zoologists. And I loved it! Honestly and truly that was absolutely the right thing. (Lesley, Interview 1)

I was actually offered a position [to study music], but I didn’t want to go to [name of place] so I turned that down. And the next thing was [a different place] and English just wasn’t my strong thing and if you didn’t do English, what else did you do? You did science. I didn’t know that there were any other options. (Alice, Interview 2)

While this was clearly a successful choice for Lesley, Alice went on to describe some very dull and abstract learning. She gave as an example her detailed learning about theoretical issues in statistical sampling for ecological studies, without the associated field studies that would bring the theory to life. She saw “no point to it” (Interview 2). Zoe also expressed disappointment in her learning experiences at university:

University was a dreadfully long time ago and we didn’t do a lot of practical hands-on, related to the outside world stuff. It was, a lot more, like our zoology, you know you’re doing dissections of fish and species that aren’t even native, those sorts of things. Which was good I suppose—you weren’t cutting up native animals. But you know a lot of my degree was actually on much more generic topics that didn’t really hook me in, in terms of local relevance or personal relevance. (Zoe, Interview 2)
These comments echo Sarah’s disappointment with ecology at university (see Section 5), yet Alice, Zoe, and Sarah all went on to be passionate about teaching ecology before and after their fellowship years. Sarah and Zoe’s seeming contradictory choices may have come down to youthful idealism:

And I was naive, we all are, I guess, at that age [on leaving school—in her case a Catholic girls’ school]. But that was one side, that I thought ‘Well look I can help people’. The other side was ‘I love science and I think I can do this’. So that was the two parts to it—to becoming a teacher. (Sarah, Interview 1)

Both my parents were teachers, well still are. And for teaching I sort of understood about working with students and things a little bit—it was part of our lives as young ones. And I think after having done my science degree, what I was trained in was really in laboratory work. By the end of that, and I realised that I wanted to offer a little bit more. I wanted more people contact. . . . I enjoy science and I enjoy science thinking, but I had always been a bit of a greenie as well and like the social aspects of things. And so I thought I could sort of bundle everything in together. (Zoe, Interview 1)

Alice expressed similar ideals in relation to her teaching. These comments were something of a lament because she felt she was no longer able to teach as she wished in the changed context of the school to which she returned after her fellowship. At the time of this interview, she had left teaching after only one term back at school, and was feeling very sad:

Those kids are coming in with certain values and certain ideas. Those are the important things to change around the ideas and the values that you want, not the content. . . . Just respect really, respect for the environment, respect for people. . . . Give kids an idea of what is of value in the place that they live in. That has gone [from the classroom]. (Alice, Interview 3)

Again, these associations between choosing science and a desire on the part of females to choose a “helping” career could have been predicted (see, for example, Jones et al. 2000). My interest is in the impact of these aspects of my participants’ “being” on the ways they re-present science to their students. I return to this question shortly.

Teaching as a default choice
Notwithstanding her idealism, Sarah at one point said she went into teaching because:

I didn’t do as well academically as I would like to have done, so the opportunities to go and do postgrad or Masters weren’t there for me. And there was no funding in those days. You couldn’t get loans. And so I had to go and get a job. (Interview 1)
There were elements of default thinking (or at least rethinking) in the choices made by Lesley and Alice as well. Lesley initially tried lab technician work but, like Zoe, quickly decided it was not for her. Both she and Alice stumbled into teaching and found it a very powerful experience:

I was never going to be a teacher—never, ever, ever! And then I ended up doing relief teaching at some point in my career because I was between jobs and they were taking people off the street—they were desperate for science people. And you have that aha experience. You know that—you explain something to a kid and they—I understand it! And you feel so good. And I don’t think any other job I have ever had has given me that ‘aha’ experience. (Lesley, Interview 3)

Well, certainly when I finished university, the last thing I was going to do was be a teacher. Then a friend who I sat at kindy with when I had three kids, and she had kids, and she was a teacher. And I was moaning and groaning about the standards of teaching and she said ‘Well unless you are prepared to get in there and help I don’t think you have the right to criticise.’ And I looked at her and I thought ‘Oh you beggar! Right—I will prove to you that I can teach’ (laughs). . . . If I hadn’t had children it might have been very different. I don’t think I would have gone teaching. I think it’s the family/children perspective that made me want to go and that put me into teaching. . . . And an interest in how they learn. I mean I’d had no interest in that previously, none whatsoever. And it was my own children that awakened that idea of how do you do this? Why did that kid do that? (Alice, Interview 1)

Ambivalence about actual participation in science
Passion for telling students about science, and specifically for advocating for the natural world and its protection, seemed to sit in a somewhat uneasy juxtaposition with a degree of personal ambivalence in all six female teachers’ personal relationships to science as something they could actually “do”. The extent of their self-doubt was a noticeable theme of the early interviews with all except Zoe (whose fellowship was more focused on educational research than on science per se).

Alice expressed her diffidence by speaking of herself as an amateur naturalist who might make mistakes whereas “a professional [scientist] would know they were right” (Interview 2, my emphasis). She then added that part of her uncertainty might be because “Of course I don’t know whether what I’m looking at is what they are looking at” (Interview 2). By the third interview her sense of herself as a confident knower had been somewhat restored. “Gaining confidence was incredible. Being able to talk with people, being respected by people, for what I was, for who I was. ... I certainly feel now that the knowledge I have is valued and I didn’t know what knowledge I had before” (Interview 3).
Lesley similarly expressed reservations during the first interview about whether she would be successful in her research project. She had become aware just how “meticulous you have to be to ensure that you have—you know all the little steps” when sequencing precious DNA samples that could not easily be replaced. Nor did the weight of responsibility lessen when she became “more aware now just how much everything costs” (Interview 2). Looking back after her return to school, she commented on the strong feelings evoked by this early lack of confidence:

At the beginning of the year I felt—there were a couple of times when my mentor had greater faith in me than I had in myself, I think. And he showed me how to do something and then he left me to it. The first time I ran a gel completely on my own I felt ahh . . . really I was quite—you quiver a bit at it all. And the same thing with some of the other techniques. The first time you have a go, yes you feel very powerless. You feel like—it’s not a comfortable feeling. (Lesley, Interview 3)

During her first interview, Halifax said she initially felt she would be “a bit of an appendage” because she didn’t have the expertise. She had expected to be a “bit of a gopher”. However at the time of the interview she had already found herself “in the hot seat”. Because of the reading she had been doing she already knew more about her research question than the scientists. She said this made her feel the “weight of the responsibility but also a sense of excitement. This is real.” She was preparing to present her proposal and the findings of her literature search to a group of managers and she was very nervous about the prospect. During the second interview she reflected on how this had worked out in practice:

It worked out very well and of course once it was over I felt ‘how stupid’ to have got really so worked up about this. . . . We [ set an extraordinarily high standard of performance, of knowledge, of all sorts of different abilities. . . . I always like to feel that I am as well prepared as I could possibly be. That I will be able to field any questions and that sort of thing. . . . I couldn’t get my head around the fact that even though I had been involved for only a very short period of time, I probably would indeed know more about those particular issues than they. They were very accommodating and made the whole thing quite comfortable for me to be able to deal with. (Halifax, Interview 2)

The weight of responsibility to be both a confident and knowledgeable performer is very evident in this comment. During her second interview Halifax explicitly likened teaching to “being a little bit like an actor and in the mornings, probably actually even before we even get to staff briefing, we’ve put on our costume, and we are
following a role and trotting out the patter”. Interestingly, she said that this role might be somewhat different with different classes and she also acknowledged that:

I guess that a lot of the things that I have been doing this [fellowship] year I haven’t really quite known what my lines were beforehand. I haven’t really known whether the costume that I was going to wear was appropriate. And so that was really quite challenging. But it has made me think a lot more about what I do in the classroom. It has also made me think a great deal more about how we prepare our students for outside of school. (Halifax, Interview 2)

The final line illustrates how the thoughts of a reflective teacher may quickly turn to ethical concern for their students. In this case that concern turned on the need for students to be confident and with a strong sense of autonomy in their work ethic, if they were to gain fulfilling employment. Yet when I asked Halifax if she could put her finger on aspects of teaching practice that worried her most in this regard, she laughed and said “I haven’t really come up with anything”. While she felt the ethical challenge, it may be that the complex dimensions of co-participation in the classroom were not sufficiently clear for her to make any conscious decisions on which she could act. Here are echoes of Barnett’s challenge. What can teachers actually do to help students make a confident “investment in their own selves”? What are the implications for attempting to do so in the context of learning science and learning about science (NOS), when these teachers do not seem to be particularly confidently invested in their own science abilities? These questions have pedagogical implications, especially in view of the challenges posed by interobjectivist models of teaching such as enactivism (see also Section 7).

Recent experimental research, using techniques from psychotherapy to allow a “double” reading of women’s stories about their personal relationships with science, hints at even more complexities (Gilbert & Calvert 2003). The women scientists with whom Jane Gilbert and Sarah Calvert worked chose science in the expectation of gaining access to a powerful knowledge system that would ensure a degree of status and control in their lives that set them apart from their mothers and other older women. Interestingly, some of them did not enjoy the messy realities they found in real science situations because this was not part of the image that attracted them to science in the first place. Nor did Gilbert and Calvert’s women scientists find the power they expected, with many of them relegated to “helper” roles to male scientists. Some of them had already moved into other career fields, yet the
ambivalence at the heart of their relationship with science was not clear to them before they took part in the lengthy research conversations. Gilbert and Calvert suggest that research of gender issues such as that reported above (Baker & Leary 1995; Jones et al. 2000) “leaves out a range of other factors that, it seems to us, are important” (p.862) They argue that males and females working in the sciences experience issues of power differently from one another, especially in regard to the “masculine” ways science is constructed as a knowledge system. Although the gender question was not central to my research, and the imbalance between male and female participants was accidental (see Section 1), it does seem to me that “being” a female and a science teacher may be a more conflicted position than it is for males.

Ross’s responses to the same types of uncertainties as expressed by the female teachers make an interesting contrast. A primary school teacher, he said that science was “not a subject that I really naturally excelled in at school. In fact I had to openly confess to the scientists at [name of place] that the last time I really had any in-depth input in science myself was probably in the fifth form” (Interview 1). And yet, like Mark, he seemed to revel in the opportunity to plunge in and learn from others:

I asked a heap of lot of questions. Thousands of questions! And I think one of the things I have learnt from that is to never devalue somebody who asks a question, because a lot of my questions were—I think some of them were pretty basic initially. And some of them were probably thought provoking and deeper as time went on. And I appreciated the people who I was working with, that I never felt put down or anything like that. They were more than happy to answer them. . . . I was asking the questions that I needed answers to. This was my development and I could see my growth and I could see the jigsaw pieces sort of all coming together. (Ross, Interview 3)

Thus my participants’ candid personal narratives reveal a complex mix of factors that might come into play in shaping their “being” as classroom teachers of science. Some factors seem to be deeply embodied in gendered experiences and relationships, with science itself. While I think it would be helpful to support teachers to explore these issues, this also seems an unproductive starting point for NOS conversations, which can be unsettling and threatening in their own right. And so, in the next part of this section I refocus the analysis to suggest a quite different interpretation of the meaning of the diffidence expressed by the female teachers, in the process employing a more explicitly ontological theoretical framing. I take my mandate to do so from the philosophical perspectives of pragmatism, where the measure of which “truth” to
adopt resides in the consequences that follow (for a model of such multiple interpretation see Cherryholmes 1999).

Identity narratives and commitments to science teaching

A nondualist ontology places the mind inside the brain. As an organ it is no less restricted by its basic biology than, say, the liver or the heart. Davis, Sumara and Luce-Kapler (2000) review what is known about the brain’s perception abilities and link these biological insights to the challenges of helping beginning teachers learn to teach. They report that what appear to be conscious decisions are actually after-the-fact justifications of decision-making processes. This is because decisions involve “the entire brain—which means that, although we can and do make our own decisions, most of the mulling over, the weighing of options, the debating, and so on are simply not present to consciousness” (p.21, emphasis in original). Davis et al. then explore the implications of these biological insights for learning to teach in the first place or making changes in established teaching practices:

Learning to teach and transforming one’s teaching practices, then, are not simple matters of deliberately selecting and enacting particular pedagogical strategies. They are, rather, complex matters of embodying different habits of perception, of speaking, of theorizing, and of acting. Although involving consciousness, such learning must be understood as vastly more complex than consciousness can possibly monitor (or that textbooks can possibly describe). (Davis et al. 2000, p.23)

Two of the teachers indicated some awareness of the embodied nature of teacher knowledge, although neither of them really developed this line of thinking and I was not sufficiently alert to the possibility to try and draw it out at the time:

It wasn’t as bad as I thought, getting back to school. It was a wee bit like riding a bike. Once you got back into it, you realised that you could do it after all. (Ross, Interview 3)

And I feel, after last year, that perhaps we should be asking some questions….That sort of accepting change. I’m doing what I can. And sometimes not even consciously doing what I need to do to remain true to the subconscious decisions I made last year really, about what education is going to be all about for me and my students. (Zoe, Interview 3)

Gilbert and Calvert (2003) found many contradictions and complexities operating at the subconscious level for the female scientists in their research. I do not have the skills in psychotherapy that they employed, nor did my research use the requisite
methodological approach. Nevertheless I can see hints of interesting subconscious influences on my participants’ thinking about their teaching. While more speculative, the following insights are helpful because, as I will subsequently show, they lead to a way forward with the NOS question at the heart of the thesis.

**Learning and teaching as passionate acts**

Daniel Liston (2004) makes thought provoking links between passionate acts of learning and falling in love. Both situations, he says, make us feel “intensely alive” (p.460). Both necessitate a risky seeking out, moving from the known to the unknown, in the process traversing a “space of desire” where we “reach out to know, yearning to fill in and reconstruct those parts of ourselves that remain open and alterable” (p.465). However, such “coming to know seems to inevitably entail, at some point, a sense of insufficiency” (p.462). Thus there are risks, but also potentially, great rewards. I found the following observation about the balance between those factors particularly thought provoking:

> The lure of learning holds forth success, failure and other outcomes in between. Failure can be frustrating, and repeated failure can lead to self-doubt. But if the lure of learning always promised achievement, I doubt it would hold much attraction. (Liston 2004, p.466)

As learners, my teachers did on occasion candidly express self-doubt, but they also described the power of overcoming these doubts when they were ultimately successful in meeting their goals. Listen, for instance to Halifax, who, as we have seen, got herself so worked up in the early stages of her project:

> It was such a challenging year in so many ways. I think mainly because I had chosen to go into something that I knew nothing about. I didn’t realise it would be quite so challenging. I didn’t realise I would be so much on my own. And so there were lots of things that I had to do, that I would otherwise have never have thought I would take on. It was wonderful! I really enjoyed it! It was terrifying. Totally terrifying! (both laugh). Some aspects of it. But as the year went on I could feel within myself that confidence and feeling that—well if I can do that I can do anything. If I can do that, I can certainly do that. And a number of times I felt that, for the future, this experience I would always be able to come back to. To touch base—to think to myself, I was able to take this on. I was able to carry it out successfully. Nothing else surely can faze me. (Halifax, Interview 3)

And here is Lesley, who was initially unsure if her level of physical fitness would be up to the challenges of going on a fieldtrip to a remote location, and who also faced considerable challenges in her lab work:
It was wonderful. The weather was shocking, absolutely shocking. I was wearing five layers on the top and three layers on the bottom and all the rest of it. I mean, we were in a field camp. . . . I was just so glad I went. It was a really magic experience. (Lesley, Interview 3)

Probably about a fifth of the time when I was extracting DNA from blood samples, you wouldn’t see the DNA precipitate, but you would go ahead and act as if it was there, and it was. Those were great leaps of faith. (Lesley, Interview 4)

The lure of successful learning and action, the attraction that can make powerful learning so addictive (see also Schallert, Reed & Turner 2004) is obvious in these comments. But Liston does not stop there. His purpose, after all, is to explore times when teaching is a passionate act:

As teachers we are attempting to enable students to reach beyond their boundaries to something that has given us intrigue, understanding and sustenance for our imagination. It is an intellectual, emotional, and at times physical attraction that we want to share, so we invite students to be attracted by some ‘great thing’. . . . It is an invitation that comes from our depths, from who we are intellectually, emotionally, and, for some, spiritually. When we ask students to consider material, material that lures us, we are exposing parts of ourselves for others to see. This makes us vulnerable. In inviting students to share our love of learning, we are inviting them to share in who we are (Liston 2004, p.467, emphasis added)

For all of my teacher fellows that “great thing” was their love of the natural world, the development of the explanatory stories of science that intensified their own sense of its delights, and their enacted passion for its conservation. Having their students experience this world directly was important to all of them, even when they saw obstacles to actually doing so. In their different ways, Zoe, Ross, and Halifax all capture this passion here:

The other day on our camp we took the biology and the environmental studies students out to [name] for two nights. And we camped out in the bush one night. And we had found a possum on the road—which was the closest thing they could find to a live one in the trees—and we took it down and they left the entrails in the stream to see what would happen. To see if it would attract the eels, and we could watch the eels. And looking at the faces of the students as they were watching the eels try to deal with their food. And yeah, the look on their faces when the kids saw a keruru or a fantail up close. Those sorts of things—that sense of awe. And one of those students particularly has just been buzzing all week since then. Asking all sorts of questions about everything related—and not related to that. It’s just stimulated her curiosity, wanting to find out, wanting to know about all sorts of things. (Zoe, Interview 3)

I found a record of possum predating little chicks—nasty little video clips, you know. Only a few seconds long but a sequence of them all showing these horrible little predators doing their nasty business. . . . Well I think they have quite an impact! I’ve
always known that kids really like those sorts of things so I suppose just having had some time away to be able to put my finger on some of those things. The kids love them. They are fascinated. They are awestruck. And they think they are shocking— disgusting, dreadful. It makes a lot more impact than just me telling them about it. (Zoe, Interview 4)

[A scientific attitude is] enthusiasm, it’s curiosity, it’s that life-long learning—you know they will carry on learning outside of school time because they want to, not because they have to. It’s about having an open mind about results, and being willing to change your point of view. It’s about—probably about thinking critically, not giving up, those kinds of things. ... I think fostering is what you are doing with enthusiasm and curiosity. Like at school I have had just a few simple things on the table, magnifying glasses, 3D viewers and some tuning forks and I showed the children how they could encourage spiders to come out of their webs by hitting a tuning fork onto the web. That kept some kids going for weeks on end (chuckles). (Ross, Interview 3)

… the practicals that you can do such as gel electrophoresis, and DNA extraction, seem to—I find them exciting. Even now, even though I’ve done them many times. . . . And students always, without exception, every year will—the wow factor of extracting DNA. ‘Wow! ! Is that really DNA?! ‘ . . . That’s just so exciting. (Halifax, Interview 1)

Some felt it was important that they shared with students the power of overcoming uncertainty in learning:

I’ve learnt a great deal in terms of being able to support students in terms of their scientific investigations. The questioning for instance. If you don’t know the questions to ask, or if you’re put in a situation where you are feeling very much on the back foot because you’re feeling you know so little, and you’re worried that you’re going to make a major fool of yourself, the importance of actually baring your soul and not worrying. It’s just convincing yourself that you may well appear to be a bit of a fool but it really doesn’t matter because by doing that you will get what you want. (Halifax, Interview 3)

In terms of scientific method and things it can be very dry. But it’s also a wonderful freedom to actually get—to think ‘Oh what are you going to do?’ ‘How are you going to find it out?’ And, too, that sense of awe and curiosity—and the willingness to go and find the answers to the questions that arise. I think that’s what I consider the attitudes that are important. (Zoe, Interview 3)

Words that convey emotions abound in the above comments and in those in Section 5. Here are passion, awe, wonder, excitement, enthusiasm but also worry, shock, and disgust. And the focus of all that emotion is the natural world and the use of science as a way of investigating it. These “things” and “experiences” are the focus of the teachers’ attention as they share with their students something of “who they are”. Those aspects they cannot experience or investigate may have less allure for them and for their teaching:
Oh I’m astigmatic and I can’t really see the stars and so it is just something, it hasn’t grabbed me and it hasn’t grabbed my imagination yet. I know that many people—I know that it does others. But I know of everything I have to teach, I do the worst job on that one. (Lesley, Interview 2)

Five of my participants carried out projects with strong outdoor experiential components. Section 5 discussed Sarah and Bridie’s perceptions that these experiences had changed their ability to observe aspects of this world in an embodied way, so that the change had become “part of them” now. A passion for the environment and its protection was well matched to all five participants’ deep enjoyment of being outdoors, and their investigative challenges related to designing and enacting protocols for measuring and monitoring aspects of the natural world in all its experienced complexity.

The other three participants spent more of their time in laboratory settings. However the experience of actively investigating an aspect of the world was just as powerful for them as the outdoor experiences were for the others. Here Mark responds to my question about “powerful” aspects of his fellowship learning:

Some of the new equipment was interesting to work with. And I hadn’t used—obviously it had changed since I was at university myself So that was really interesting. I was learning how to use computers to manipulate samples – HPLC machines and things like that. . . . The principles haven’t changed much. I was basically just using a column that’s grabbing material as it’s going through and you just flush it out later. And you just make the reading—it’s all computer-driven of course which is easier. . . . But the way it is done is a bit different. So it was quite interesting to learn all that new technology and working through to find out the results and get a standard curve and all that stuff (Mark, Interview 3)

Both Mark and Lesley saw this experiential investment as something that would enhance their teaching, and even perhaps their identity as a teacher:

All those techniques that I talk about from Year 13 Bio, you know, it’s just such a wonderful thing to be able to do them. . . . I can understand it better when I actually have dealt with it. (Lesley, Interview 1)

I’ve always been pretty keen on making sure they [students] are scientifically sound in their research methodology but it’s having had that practical experience and being able to say ‘This is what I did at [host organisation].’ They recognise that. Often students don’t see their teachers—their science teachers—as scientists. (Mark, Interview 3)

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11 High performance liquid chromatography.
Lesley spoke of the felt intensity of anchoring ideas about DNA analysis in context. As the next two comments show, context for her related to both the laboratory setting, and to direct experience of the environmental issue that underpinned her investigation:

I was just absolutely blown away, the day I was in the sequencing lab the technician there had received a new shipment of the big dye, that is the fluorescently tagged [inaudible] - nucleotides that they use for the sequencing and it was in this huge box, you know, just absolutely huge. I kind of think of it, about you know 600 by 400, and inside it was a little box. This is all ice and been shipped from Sydney and in that was a little plastic phial, it must have been 250 maybe 500 mls. max, all inside this enormous thing and she said this is $56,000 worth of reagent. (Lesley, Interview 2)

Since I talked to you the first time, I have been out in the field with [name of person, area and species]. They use that [species] as a model for most of the work that goes on, on the more endangered species. And you know that was really worthwhile because you get a better idea—I mean—okay, when I am in the lab I have little tubes of blood and that is it. (Lesley, Interview 2)

Part of the allure may be the challenge of actually getting a complex investigative process to work as intended:

I quite like experiments that have an element of—they may not work. The gel electrophoresis separation is always—J keep everything crossed, and it doesn’t necessarily always work. (Halifax, Interview 1)

A related affective aspect was being immersed in learning of one’s own choosing and persisting through the difficulties raised:

I think that always makes a huge difference if you have got some ownership of the topic and you’re passionate about it. You’re going to push through those hard times and the things that are difficult to complete the task. (Ross, Interview 2)

I was really discouraged at the beginning because I kept hitting dead ends with—as I tried to teach myself how to use this program [a bioinformatics program for genomic analysis]. And now I have got to the point where I can show what I am doing. Because I am using a different program from what some of the other people are using - ‘ Oh that’s pretty good! Wow! ’ - you know. And so yeah that part of it, the feeling of satisfaction that you could come to terms with it. That has been really good. (Lesley, Interview 2)

An NOS with an epistemological orientation, focused on abstract ideas related to “working scientifically”, while clearly relevant to the investigative processes used in each inquiry, seems unlikely to be of sufficient passionate concern to the teachers quoted here that it could persuade them to change their practice. The strong feelings
that compel them as science teachers are bound up in a desire to have students enjoy a certain intensity in their science learning that is related to direct experience of investigations of the natural world in the context of personally compelling questions.

The perceived and enacted need to take better care of the natural world provides an urgent ethical dimension of these teachers’ practice. In this situation, it seems likely that a NOS that focuses more on the complexities of the “real world”—i.e. a NOS with an ontological orientation—could be more compelling for teachers, especially if they could see it making a difference to their students’ ethic of care for the natural world as well. I suggest we should work with, rather than against, teachers’ passion for sharing their concern for, and interest in, the natural world when developing new approaches to NOS teaching.

**Ontological options for re-presenting the natural world**

When Halifax produces DNA to wow her students, aspects of an “ontological reversal” (Dahlin 2004) can be seen to be at work. There are real chemical procedures, beginning with real living material (for example mashed up vegetable matter), and ending with the triumphant appearance of those equally real, slender white threads twirled out of the test tube on a stirring rod, then pronounced to be DNA. What goes on in the intermediate stages—the “chain of transformations” to use Latour’s (1999) term, must be taken on faith. To do otherwise would be to spoil the powerful moment. DNA, with all its theoretical complexities and historically changing metaphors (Fox-Keller 1995) becomes an unproblematic “really real” thing. We can see it! We watched it appear! Why would anyone ask for more, or undermine that magical and motivating moment with qualifications about the contingent nature of construction of the reality at hand?

I have read other descriptions of science teaching that invoke the same passion in the demonstration of a science idea as the episode sketched so briefly here. For example, Gunther Kress and his colleagues recently carried out a detailed analysis of the semiotics of meaning making in a typical science lesson (Kress et al. 2001). One analysis described in some detail what the teacher did as she explained the way the human heart works. Even her body was pressed into service when, at one point, she stood in front of the whiteboard diagram, her own living, beating heart momentarily
superimposed on the two-dimensional explanation. Two things struck me about this analysis. The first was that it rang true. As someone who once taught human biology, I could see myself doing everything that teacher did, saying everything she said. The second was that the analysis highlighted the complexity and deeply embodied nature of her work. I suspect any ordinary teacher reading that analysis would be astonished at what they can do, and regularly do, without conscious thought.

Here is the very essence of a complex dilemma for those concerned with NOS reforms in science teaching. As outlined above, science teachers’ enacted passion is for a real world of things, presented along with the marvellous explanatory ideas that have allowed the mysteries of that world to be harnessed in so many interesting (and destructive) ways. In the context of a traditional epistemological framework, that passion to show and explain seems to direct teachers to the strongly realist end of the continuum of epistemological possibilities (see Section 3). As if the difficulties of relativism implicit in more idealist epistemologies were not enough (also outlined in Section 3), this alone could be sufficient to reinforce the status quo and cause teachers to eschew epistemologically-focused NOS interventions.

And yet there is something else here—something that doesn’t quite fit. If we listen hard, there is one discordant note in the realist epistemological match to their teaching practice. As we have seen, the identity narratives of the teachers in this study have an interesting ethical thread. They don’t just want their students to know. They want them to care as much as they do, not just about the exciting moments (although those are obviously constructed to prompt a positive affective response) but also about the concerning impacts on the natural world of technologically driven human activities. At least implicitly, the teachers are also seeking an ethical dimension in students’ responses to their learning. Their own science knowing has both ethical and political dimensions that are suggestive of a personally weaker ontology than their classroom positioning seems to allow. They are not “Teflon subjects” (White 2000). Could this discordant note present the opportunity of a more effective entry point for encouraging them to introduce NOS components into their teaching?

Could personal ontologies of a weaker variety be powerfully aligned with newer ontologies of science, such as those outlined at the end of Section 3? This speculative
question points to the need to introduce an ontological perspective that emphatically maintains a “really real” world in all its vivid intensity while at the same time undermining tacit epistemological assumptions about one true way of knowing, as entailed in a strong ontology. A potential means of beginning to do so in a manageable fashion is explored in Section 7.
7. NOS in the classroom: ontology, not just epistemology

We believe that understanding is not most commonly driven by practical or instrumental purposes. The desire for understanding is driven by something more human. It is in our nature to seek connections—connections to others, to the earth, to important ideas. This sense of connectedness is not only at the level of individual cognition; it comes from a desire to know with one’s heart and mind, emotions and cognitions, imagination and reason. (Girod, Rau & Schepige 2003, p.577, emphasis in original)

Introduction

Connectedness is at the heart of this section, both as an educational focus, and as an intention to tie the wide-ranging threads of the thesis together. I have argued that an ontologically-focused approach might provide a more accessible entry point to NOS ideas than epistemology has proved to be thus far (Sections 3 and 6). Keeping my thoughts close to the passionate concerns of my participants (Sections 5 and 6), I want to see if I can make a space for them to engage as science enthusiasts while simultaneously making room for students’ ideas and concerns to be more systematically taken into account.

As Section 2 outlined, the broad intention behind the inclusion of NOS as a component of science education relates to helping students see the relevance of science in their lives, while also helping them build a more accurate picture of the way science actually works. I have argued that adopting an ontological entry point for NOS explorations will bring these two aspects together to help students see how science actually works in the world. To do so, conventional views of science need to be replaced with what John Ziman (2000) calls a “meta-science” model that includes the ethical, social, and human questions implicated in science activities. This NOS model cannot just be about science as an “objective” type of knowledge building, for as Latour and other sociologists and anthropologists of science have so convincingly demonstrated, science is deeply enmeshed in the networks that unite humans with all the other members of our natural and technological worlds (Sections 3 and 4).
Encouragingly, I find I am not alone in my quest for a more ecological or networked type of NOS. Laura Colluci-Gray and her colleagues (2006) have very recently called for a rethinking of the meaning of scientific literacy and a linking of meta-science to a “notion of complexity of the educational process” (p.229) in order to motivate and engage students with every facet of science at work in the world, including social and ethical concerns. However, this is, I suspect, easier said than done. The challenge is to find ways to introduce NOS ideas from an ontological perspective without in the process introducing the spectre of relativism (Sections 3 and 4), or requiring teachers to first top up a deficit fund of epistemological knowledge (Section 2).

There are two parts to the discussion that follows. I begin by looking at matters of timing and curriculum sequencing. If NOS is to have both ontological and epistemological aspects, how should these stand in relation to each other, and to other aspects of students’ science learning? Following that, I address an important practicality. What form might classroom activities take if a more explicitly ontological approach is to be meaningfully and manageably achieved as an entry point to NOS learning? Where others have advocated the use of role-play (Colucci-Gray et al. 2006) I have a more modest starting point in mind. I want to keep my proposed entry-point activities as simple as possible, at least in principle. The philosophical challenges in understanding how the nature of science has changed rapidly in recent years are substantial (Section 3). I hope to minimise the risk that lack of familiarity with the broad teaching approach will also be a barrier to change.

**Ontology as an initial context for NOS learning**

Complexity science asserts that our knowledge systems are rooted in our physical forms—and that those forms, in turn, are engaged in ongoing cyclings of matter with all other living forms. Oriented by this realization, science has mounted a case against itself in the accumulation of evidence that many current personal, cultural, and planetary distresses can be traced to scientifically enabled human activities. It does not seem unreasonable to suggest that something other than an explanation-seeking scientific attitude is required for an effective response. Knowledge is useful here, but wisdom is needed. (Davis 2004, p.156, emphases added)

Reflections such as this point to an ethical need to go beyond a traditional epistemological focus when introducing NOS ideas to students. Would a more direct focus on the situated complexities of the natural world provide a more productive
beginning point to seeking “something other” than the traditional curriculum concern for abstract explanatory detail? Section 6 suggested such a focus might better align NOS explorations with teachers’ passionate concerns. I now scope how I think this might play out in practice.

Several years ago I suggested that “situation specific descriptive detail” is often neglected in teaching the “what” of science (Hipkins 2001, p.267). Episodes from my teacher education experience informed that argument. For example, a conversation about why northern hemisphere texts and resources would need to be adapted when teaching about phases of the moon in New Zealand schools led one physics major in my class to burst out in frustration “But Rose, they never taught us that stuff!”

Taking my cue from an eminent biologist (Mayr 1997) I argued:

Let’s also put back the simplest piece of all (and the referent without which there would be no science!) The ‘what’ of the natural world should always sit alongside and inform the ‘how’ and ‘why’ in science education. (Hipkins 2001, p.276)

I want to pick this argument up again and see if I can develop it further in the context of the NOS question. The next two figures compare what I see as quite different learning approaches to NOS. Figure 3 is more traditional and takes situation-specific content as merely a beginning point. Such a pathway is, I think, congruent with the development of a more traditional epistemology, aligned with a realist ontology, although this is unlikely to be an explicit learning focus.

Figure 3 A traditional pathway to NOS learning

In this model, familiarity with the “what” of science is simply a necessary (if sometimes neglected or taken for granted) step towards the end of gaining more theoretical understandings. In this model, epistemological ideas about science sit at the end of a continuum of abstraction. I think this relationship has predictable consequences for teachers’ curriculum decision making. At the end of a chain,
preceded by “content” as usual, NOS is rendered vulnerable to being ignored. This new focus need not interrupt teachers’ traditional curriculum thinking, and as Section 2 showed, this type of NOS is indeed ignored by many teachers.

Because epistemological ideas about science sit at the end of a continuum of abstraction, they may also be difficult to access unless and until the other pieces of the knowledge chain are in place. Something of this can be seen in the experiences of working with teachers recounted by Ryder and Leach (2005). One set of the NOS materials they had previously researched and prepared used electromagnetism as a context but, when observing teachers using these materials, the researchers noted that “many students struggled to understanding [sic] the science content and this overshadowed the epistemic learning aims of the lesson” (p.10). Yet, perversely, knowing more about the content was disadvantageous in a different way. Ryder and his colleagues also found that when using a set of materials related to cell membranes, students had difficulty setting aside what they already knew of theories of their structure, in order to think about the evidence as the scientists of earlier times might have done.

This dilemma recalls Latour’ s discussion of the ontological work done as new ideas remake the world (see Section 4). Underscoring the impact of a non-dualistic ontological perspective, Davis puts it thus: “Each event of learning entails a physical transformation of the brain; hence subsequent events of learning are met by a different brain” (Davis 2004, p.165). As he also points out, descriptions of the universe are part of the universe. As descriptions change, so does the universe itself (p.101). Materials that ask students to think as if they did not know certain science ideas may make epistemological NOS understandings seem even harder than they apparently already are. On the other hand, the “problem” could be recast as an ontological learning opportunity, if students focused instead on how the ideas in question changed the way that aspect of the world has been seen ever since. I will come back to this idea shortly.

Davis defines a “participatory epistemology” as an attitude that sees interconnections and understands knowledge to be an “ever unfolding choreography of action within the universe” (p.101). I think this resonates with White’s idea of a weak ontology that is consciously built and actively maintained (see Section 6). I wonder if a
disposition towards a participatory epistemology, coupled with active maintenance of a weak ontology, might avoid both types of traditional NOS teaching issue (students knowing too much or not knowing enough content in advance). Exploring ways key science ideas connect to and remake the world of lived experience would keep the learning focus closer to the natural world and better link more abstract ideas to the local detail that gives them personal meaning and usefulness. As Section 2 outlined, such an approach would be congruent with sociocultural advocacy for changes in NOS teaching, and indeed science teaching generally. Sections 5 and 6 showed my participants’ passions tend toward ideas that more directly link science to the natural world and I expect this is likely to be so for both other teachers and their students. But how might this play out in actual curriculum sequences? Figure 4 shows broadly what I have in mind.

Figure 4 A non-dualistic, participatory pathway to NOS learning

The model I propose is congruent with sociocultural views of learning and complexivist views of knowledge. It challenges views of curriculum as pre-specifiable “content”. Ideas arise in the contexts of their use and cannot be separated from them. Students are participants in these contexts and in this type of NOS there is a “felt reciprocity” in their relations to “things and to the earth” (Colucci-Gray et al. 2006, p.230). Here, then, might be a space for my teachers’ passionate concerns to make links to new ways of teaching for NOS. More challengingly, the model also implies “just-in-time” rather than “just-in-case” approaches to curriculum and learning—approaches that are now common in the business world but still seem to be unfamiliar to many teachers (Gilbert 2005). Within this model, curriculum cannot be content coverage as usual. This suggests that implementation challenges would be substantial.

There is another caution to be sounded here. A critic of this model could rightly argue that it makes no place for the “how” and “why” of science, or for traditional
NOS approaches, all of which can make for compelling and interesting learning, too. I agree, albeit with the qualifications already expressed as the thesis has unfolded. And so my next challenge is to see if I can integrate these pathways in some way, to get the best of both approaches.

![Diagram](image)

**Figure 5** Taking a “both/and” approach to NOS learning pathways

The alternative approach I propose here always begins with a focus on the “what” of the natural world in all its vivid appeal to my teachers and (they hope) their students. Rich experiences of phenomena underpin and precede a range of possible ways of further developing both science “content” and NOS understandings. While my own preference would be to fully develop the more participatory pathway first, more traditional approaches are not precluded, and may indeed present opportunistically as learning unfolds. The double-headed arrows capture the meta-science idea that “the relationship between science and society has never been simple or unidirectional” (Colucci-Gray et al. 2006, p.228).

I am particularly interested in the potential of the link between the box “connections and networks” and the box “theories of justification”. Once a network has been constructed, it seems to me a relatively easy next step to begin to identify components of the network that are observable and measurable. It then becomes possible to further expand the network by focusing on the nature of the evidence that is used to justify and support these entities and any accompanying theories of causation etc. Such matters are the standard fare of traditional epistemological NOS approaches. Thus, in making such a move, the epistemological and the ontological come to be more closely entwined. But the ideas being explored are always grounded in a concrete reality of ways knowledge works in the world rather than operating only in the realms of abstraction. How all this might work out in practice is my next focus. In what follows I attempt to construct some simple working examples of
knowledge networks or rhizomes, of the sort that students could construct in the classroom, with the help of their science teacher. I discuss ways these might be used as entry points to developing NOS ideas that take account of both ontology and epistemology.

I have chosen two topics with which to experiment. The first is global warming. What could be more important or more urgent for students to learn about? Now, for the first time in the history of our planet, humans hold in their hands the power to actually influence the weather experienced by every living thing in the years to come (Flannery 2005). What is more, as Tim Flannery points out, every one of us has the power, as an individual, to make changes that will impact positively on this complex issue. We do not have to wait for our governments to act, although obviously concerted action will be most effective. If we are serious about wanting students to become informed citizens who make appropriate choices in response to socio-scientific challenges, teaching them about this issue must be an acid test of our success as science educators.

My second topic is political in a different way. At the time of completing the written account of my thesis, New Zealand, in common with Australia, the United States of America, and possibly other nations, has been caught up in debates about the place of evolution in the school curriculum. The push to make this controversial has come from supporters of the idea of “intelligent design”. These people apparently wish to see closer links between their religious convictions and what students learn about the origins of life, but also to keep these links concealed by claiming intelligent design as a new science theory. What most interests me is that these would-be curriculum reformers have constructed clever and sophisticated (if misleading) epistemological NOS arguments for their ultimately religious cause (Terry 2004). Here then, is another acid test of the potential success of my proposed approach.

**Ontological approaches to learning about global warming**

This topic may pose challenges for science teachers if they explore it only from epistemological NOS perspectives. Here is Lesley, who chose to introduce global warming to illustrate a more abstract part of our second conversation:
Let’s take the greenhouse—you know the whole greenhouse gas system. I mean we have evidence, we have scientific fact in that we have causes and we have data that tells us how much carbon dioxide there is over periods of time and something about, you know, we know something about temperatures and things like that. Yet there are that many different opinions, theories—whatever, about the effects of our usage. Whether it is, well I mean you just take these different countries—well the different interpretations that some people place—that if we don’t cut down on our use of carbon producing—you know carbon emissions, we will be producing this. And other people are saying ‘Oh no, this is just a climatic variation—what has been going on’ etc. etc. (laughs). I don’t know where we stand—various facts—you know, we know a certain amount but then where do we take these facts? That’s opinion. (Lesley, Interview 2)

In his most recent article, Latour expresses great concern that his field of the social studies of science has been mischievously misused for the purpose of undermining the authority of science as a knowledge system (Latour 2004). He gives as an example the deliberate muddying of global warming issues by those with an interest in the continued unfettered burning of fossil fuels, including at the highest levels of the current Republican administration in America. In this and similar cases, he says, the argument for the social construction of knowledge is being turned against its originators to “destroy hard-won evidence that could save our lives” (p.227). What has happened that vital matters of politics and ethics can be represented here as being simply opinion-based?

I think this example vividly illustrates the dangers of relativist thinking if strong ontologies such as empiricist/realist views of science are swept aside and not replaced with a sophisticated and constantly tended “weak ontology” as envisioned by White (2000) (see Section 6). In any case, Section 3 argued that most science teachers simply would not be prepared to make such a hazardous intellectual journey. For his part, Latour says that this situation has arisen because of the successes of academia in critiquing what he calls “matters of fact”. In his view, ontological attention should now focus on “matters of concern”, with a view to “protect and care” for our world (p.232) rather than critiquing ways we have come to know it. Such an approach, he says, would add to reality rather than detracting from it, because there would be a “merging of matters of fact into highly complex, historically situated, richly diverse matters of concern” (p.237). He even goes on to call this a process of restoring the “thinginess” to things. This interests me because it potentially aligns with ways teachers already represent the world to their students, as illustrated by Halifax’s dramatic production of DNA (Section 6), and as also noted in the research of others (for example, Desautels & Larochelle 1998).
The challenge I set myself was to build a network model of global warming that “submerged matters of fact” within “matters of concern”. I began by focusing on the latter and Figure 6 shows the result, relatively quickly sketched after several false starts. I do not claim to have built a definitive map that logically and thoroughly connects all the possible concerns that arise from global warming. Rather, this is a personal network of issues that interest and challenge me, with some questions for the future about which I am very concerned. I think any of these questions would make an interesting topic for further research.

If I were to do this with students, I would give them the central structure, with the idea of global warming in the middle and the sea, land, and atmosphere links to alert them to the range of areas they might consider building from. I would leave the rest up to them. My intention would be to find out what they linked to these central structures, what concerned them, and what seemed to be missing. Later I might encourage the use of the internet or other resources to extend the networks and make more cross-links. I expect the actual structure of the activity, with its familiar “brainstorming” look, would be readily understood by both teachers and students. The NOS point of difference is the intention to deliberately enmesh a science issue in wider questions of how the world works (for example, the relationship between global warming and transport issues), and to show the reciprocal nature of societal and science concerns - that is, to model “meta-science” as proposed by Ziman (2000).

The analysis of this network diagram, as initially simply constructed, has the potential to reveal the complexity of the links between science, with its technological applications, and the ethical and risk questions that create the “epistemological gaps” (Barnett 2004) that make meta-science a more uncertain enterprise than traditional views of NOS would allow. To illustrate:

the accumulation of CO₂ in the atmosphere and in the oceans is the global result of a number of human activities in different “local” areas: moreover, such quantitative changes at a global scale are manifested in other local realms, and in other forms, not always known. (Colucci-Gray et al. 2006, p229, emphasis added)
Figure 6 A network exploration of global warming issues and questions. Aspects for which empirical evidence is available, or could be obtained, are tagged with an exclamation mark.
This comment succinctly captures the dilemma that we do not know what we do not know—scientists included! Students may choose to focus on the local, or the global, but without support they are unlikely to see the complexity of interactions between both. Seeking greater understanding of the impacts of our activities on others, sometimes initially quite removed from our awareness, is an important aspect of ethical thinking about socio-scientific issues—one that could be developed from discussion of a simple network diagram such as the one I have modelled here. At the local level, such awareness will need to draw on the experiential particulars of local knowledge, not just theoretical, or even empirical, science.

In Section 5 I noted that Sarah was intensely interested in the politics of the conservation project on which she worked. However she was reluctant to share this aspect with her students in case some of them had family connections to the disputes of which she was aware. Might a network diagram such as this allow her to make those links in a less personal way, showing how politics, practicalities, and conservation science inevitably intertwine? This may initially seem to her to be far removed from traditional NOS approaches that “put the emphasis on the cognitive aspects [science] . . . based on the assumption that there is a strong connection between knowledge of the topic and the solution of the problem” (Colucci-Gray et al. 2006, p.236). By showing how a range of knowledges—including but by no means limited to conventional science—potentially interact in the context of any one issue, Sarah might feel safer to open up a space for discussion of the different cultural viewpoints and values in which she was so obviously interested.

Adding epistemological links to the global warming issue

Only once I had completed the initial ontological map of global warming issues and questions did I turn my attention to the epistemological NOS question. I considered every item and marked with an exclamation mark all those where I thought observable or measurable evidence might be obtained, or where I was aware it had been obtained. It immediately became evident that “matters of fact” indeed already underpin most of these “matters of concern”. Collectively they add to a damning picture that, I think, leaves no doubt that global warming is “real”. While critics might pick off single links to create uncertainty (as for example in American Government denials that the devastating Hurricane Katrina had any link to global warming) it is the collective picture that builds the reality. As Latour noted, network
analyses are more robustly empirical, not less, than realist approaches to science (Latour 1999).

Looking to extend the empirical NOS learning opportunities further, I next tried strengthening this evidence aspect of my network. This time I made my central starting point the question “How can we observe/measure...?” and I set out four potential links:

- Changes in the weather
- Global temperatures
- Changes to ecosystems
- Carbon dioxide levels in the atmosphere.

While this is not an exhaustive list, these starting links quickly led me to a number of interesting questions, once I began building a network from this perspective. Figure 7 shows the result. I would use such a network as a stepping stone to more focused studies of selected aspects of science. Having built awareness of the interconnections, the detail of conventional science content might now be more meaningful for students. Taking the lead from students’ interests, and the teachers’ own funds of science stories and interests, it would now be possible to select “just-in-time” curriculum content for deeper exploration, but it would radiate out from NOS questions of the complexities of actual investigative processes and protocols.

Some of the links and questions in Figure 7 would be suitable for younger students to investigate. Bridie’s awareness of sampling challenges (Section 5) might attract her to similar questions in relation to species known to be endangered by global warming. Rich stories exist of how frogs are counted in mountain mist communities (for example, see Flannery 2005) and they are not too complex to be understood by even quite young children. This could lead on to an exploration of other reasons for species endangerment, which is a topic already included in New Zealand’s curriculum at the primary level. The difference would be that the practical aspects of coming to know the actual population numbers would be integral to the story, rather than the endangered status being simply presented as a “fact”.

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Some of the links in Figure 7 led me to quite deep epistemological issues of sampling and management of uncertainty. Some types of evidence are relatively easy to count once protocols have been established, while others require an understanding of complex theoretical issues before the methods even make sense. These more complex methods might lend themselves to analysis that turns them into narrative accounts of “chains of transformations” as modelled by Latour (1999) and described in Section 3.
Figure 7  A network exploration of empirical investigations that could be associated with global warming issues and questions
Thus, from the humble starting point of a network diagram, many different aspects of science and NOS might find their way into a school curriculum to be addressed at appropriate levels. In their areas of interest, each of my participants had compelling stories to tell about the practical challenges of addressing their research questions. I am confident that with access to suitable resources other science teachers would also enjoy this type of approach. Encouragingly, some science education researchers are beginning to produce such resources, or at least to undertake analyses that provide helpful theoretical guidance to the ways such materials could be structured. Ryder’s (2001) analysis of the common epistemological challenges inherent in a range of socio-scientific issues is a case in point. This type of approach to NOS could also help teachers address issues of an overfull curriculum, as recently suggested by one prominent critic of current content-focused approaches:

> If there are truly fundamental principles in science, then the extended study of any few topics in science will eventually bring students into contact with those principles. (And if not, then they were not really so fundamental, were they?) (Lemke 2005, p.8)

This comment reinforces the “just-in-time” nature of a more ontological approach to learning about science at work in the world.

To briefly recap, network diagrams of the type I have sketched here have the potential to keep the taught curriculum grounded in “matters of concern”. These become the starting point, and a type of anchor for the selection of more traditional content, including epistemological NOS aspects where appropriate, which are then explored as the learning unfolds. Because students create the initial networks, the work that follows builds on their existing interests and concerns. I see this as a means of meeting the enactivist call for “liberating constraints” (Davis 2004, p.169) in curriculum planning (see Section 6).

**Challenges to this type of activity**

Before moving to my next context, I need to address two substantive challenges to the type of learning activity with which I have begun my experimentation. I have been asked to explain how my network drawings are different from the “concept maps” of early 1990s’ approaches to constructivism, as modelled by Richard White and Richard Gunstone (1992) for example. As I understand these, the intention in concept mapping was to compare ways learners understood science concepts with the
correct way in which science would explain them. Any “misconceptions” could be identified and addressed. Thus these maps were implicitly predicated on a strong ontology and their focus was always on the cognitive. My drawings also have the potential to reveal the ways students link ideas but there the similarity ends. The aim of my networks is to explore the question of how students see the relevant science issues (first example) or NOS questions (second example) as linking to “matters of concern” in their lives and the world at large, including, if relevant, links to other science topics. My assumption is that a weaker ontology can create a more reflective space in which there is not necessarily one “right” way to do this.

The second challenge is explicitly ontological and relates to the concern of actor network theorists that the mere act of drawing a network creates a structure that seems more real than the elusive, rhizomatic nature of actual technological networks at work in the world (see Section 3). From this viewpoint my drawings can look like any other branching diagram—a long-established heuristic technique. This is an interesting challenge, but signals a pedagogical dilemma. Teachers need something substantive with which to work when engaging with students’ ideas and these drawings provide that possibility. Perhaps something of the elusive complexity of real networks might be read into a comparison of the various versions students in one class might produce. There are bound to be many differences, with some degree of overlap where particular ideas or examples are more widely shared. In complexity theorists’ terms, a degree of redundancy, along with sufficient diversity, would potentially allow for “emergent solutions” (which I see in this context as being a developing sensitivity to the ontological complexities of science at work in the world).

My second, more theoretical, response to this challenge is that diagrams with a branching structure do not necessarily need to be read as unidirectional dichotomies. Davis (2004) distinguishes between dichotomies and bifurcations. Dichotomies divide an aspect of the world into non-overlapping categories through what is presented as “ethically neutral, objective” investigation (p.10). By contrast, bifurcations highlight that when creating a branching structure, “someone is making a distinction for some reason” (p.8, emphasis in original). Thus this manner of

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12 It does not help my cause that I have not yet worked out how to draw double-headed arrows when using Inspiration.
investigation foregrounds both the *purpose* and *partiality* of the act of distinguishing, while generating fractal-like structures in which new branches are always possible, and a web-like complexity quickly emerges. It seems to me that whereas dichotomies are tacitly underpinned by a strong ontology, an altogether weaker ontology is at work in the process of bifurcation.

The profound insights into the structure of knowledge outlined in Davis’s book demonstrate the power of bifurcation as a *research* methodology. This led me to wonder if it would also provide a pedagogical means of critically exploring portions of network diagrams, drawing out their rhizomatic potential. To experiment with this idea for another ontological strategy, I have chosen a contested aspect of the first network above—the use of the “carbon sink” as a metaphor for managing greenhouse gas emissions. Gough (2002) sees the “sink” metaphor as a rhetorical device used to recruit “scientific facts” to assist the political efforts of industrialised nations to discount their greenhouse gas emissions. Bifurcation, as a method of inquiry, leads us to ask, what difference does this metaphor set up, and for what purpose was the difference created? A related question is: What do the two parts of the bifurcation have in common? Pondering these questions in the context of “carbon sinks” initially led me to the single bifurcation shown in Figure 8.

![Figure 8](image)

*Figure 8 A single bifurcation (after Davis 2004)*

Davis models the building of fractal-like new bifurcations from any or all points, which quickly leads to a web-like set of connections. In the next figure I experiment with this, to show what might be possible in my chosen context. A new thing or concept can potentially be added at the end of every line. Furthermore, as Davis points out, cross-connections are highly likely. However, in the interests of clarity in modelling the basic process, I have not included any here.
Davis says that bifurcations are attentive to the partialities associated with distinctions such as those shown here. What prejudices and biases are revealed by dividing parts of the carbon cycle in this way? How did we come to think in these ways? Who benefits from these ideas (and who does not)? Asking such questions would quickly lead students to the concerns raised by Gough (2002). In the process of finding answers, students would need to address political alliances and the work of the Kyoto protocol, the means used to co-opt public support (or not), and the ways scientists have constructed, investigated, and critiqued carbon sequestration as a means of attempting to “manage” the impact of our technological activities on the atmosphere, and hence on global temperature trends. Some branches could quickly lead to a critique of the illusion that we can stay in control by our own manipulations, obviating an urgent need to change our ways. Some branches require a pause to consider underpinning scientific theories of causation, such as the nature of the carbon cycle itself, or basic carbon chemistry. Collectively all these aspects illustrate how the four “loops” described by Latour (see Section 3) can hold together a network centered on scientific concepts that underpin the carbon cycle.

My second network sketch above illustrated how matters of concern could lead students to ask epistemological NOS questions. In bifurcation, I have illustrated how network sketches could lead to explicitly ontological questions as well. I do not underestimate the challenges that would be entailed in the introduction of bifurcation as a pedagogical approach. For one thing, Davis points out that our brains are
biologically structured in ways that give us a distributed capacity to frame the world as polar opposites (Davis 2004) so it is hard intellectual work to frame distinctions in such a different way. For another, the type of thinking modeled would require profound changes to traditional views of the science curriculum as “content” to be mastered. Nevertheless, the potential learning rewards are great, and may hold forth a lure that could align the passionate concerns of science teachers with the imperative for NOS changes in the curriculum. My preference in the short term would be to introduce models of networked thinking first, only later turning to questions of bifurcation, and then not until a body of illustrative materials had been collaboratively developed.

**Evolution vs. intelligent design: the advantages of an ontological approach**

I now turn to the second issue with which I have chosen to experiment. My next example adds to the pedagogical possibilities by showing how network diagrams can potentially be used to compare different knowledge systems, and to integrate science with learning from other curriculum areas.

In New Zealand, as in Australia, the USA, and no doubt other nations, creationism has recently been dressed up in the new guise of “intelligent design”, with its supporters urging schools to include this new “scientific theory” in the school science curriculum. All New Zealand secondary schools were supplied with a free, glossy package of curriculum materials to support this push. While the materials obviously originated from the Discovery Institute in North America, the New Zealand distributor’s religious affiliations were unclear. The materials were unsolicited and many teachers of my acquaintance simply put them in the rubbish. Such a response, however, is patently insufficient to address what has been described as a very clever marketing campaign (Terry 2004).

Meanwhile, some commentators have expressed doubts about the adequacy of the New Zealand curriculum to deal with the issue. Since its inception early in the 1990s the national science curriculum (Ministry of Education 1993) has been controversial for its constructivist approach, which some say is not sufficiently authoritarian. In the
words of one critic “being PC [politically correct] only encourages the anti-science idiots” (Haden, 2005):

Before we know it, the beggars [New Zealand’s curriculum developers] will be talking about the ‘ontology’ of science, as if that means something more than a mad philosophical attempt to distinguish between the idea of a chair and the chair itself. Such a slapdash approach potentially lets in everyone under the sun, so it is rich music to the ears of the creationists. The inheritors of the flat-earthers’ mantle want pupils to be told there is more than one theory about our origins so they can make up their own minds which one they find the most convincing. But there is only one theory, and that’s evolution. (Haden 2005, p.C 13)

This type of response vividly illustrates the difficulties raised by relativism when a traditional philosophical framework is employed (Section 3). Elsewhere in his article Frank Haden advocates ensuring that students know about the difference between a science theory and the way the word is used to mean something much more speculative in everyday life. This is precisely the sort of NOS approach that is advocated in the epistemologically-focused literature discussed in Section 2. New Zealand’s current curriculum does have a NOS strand, and could readily accommodate such an approach. But Haden, like other critics of the constructivist underpinnings of New Zealand’s current curriculum document, does not appear to realise this. In any case, my thesis participants took little notice of this strand, seemingly a common response (Loveless & Barker 2000). Additionally, this may be an area where teachers’ and students’ epistemological knowledge needs strengthening:

Among the general populace, scientific theories are perhaps the most misunderstood aspect of the nature of science, often regarded as educated guesses, or highly tentative and easily dispensable explanations about phenomena (as evidenced in evolution controversies. . .). (Dagher et al. 2004, p.735)

Zoubeida Dagher et al. argue that it is difficult to change students’ ideas about the status of theories, even when there is an explicit intention to do so, because the term is so widely and misleadingly used, even in some science textbooks (Dagher et al. 2004). Adding a more personal dimension to this reality check, I was recently interviewed on the intelligent design issue for Campbell Live, a national current affairs programme on New Zealand’s TV3 channel. Subsequently, New Zealand’s Sceptics Society gave me a “Bravo” award for clarity of public speaking on a controversial science issue. While I made the same argument about the status of theory when the piece was being taped, it is not easy to discuss epistemological
matters with “sound bite” brevity and clarity. Despite my carefully considered efforts, this aspect was not used in the edited article.

In an article for *The Australian* in response to Australian public debate about intelligent design, David Symington and Russell Tytler (2005) argue for opening up and welcoming the debate. They see its respectful exploration as a means of involving students in science rather than alienating them, as can happen when science teaching claims the high moral ground and reasserts facts and theories via traditional transmission-style pedagogy:

The science curriculum must give increasing recognition to these complexities. Scientific theories and the observations that these theories seek to explain should not be dealt with as though they arose and are applied in an ethical and social vacuum, or that the evidence underpinning the theories is unproblematic. So when the topic of evolution arises it is necessary to take seriously the fact that many of the students will want to explore the philosophical and theological issues which arise when one considers the meaning of life, and what evolution theory may or may not imply about the value we give to life, and to human life in particular. (Symington & Tytler 2005)

This comment clearly resonates with the call for science itself to address “matters of concern” not just “matters of fact” (Latour 2004). But how are teachers to approach such issues if they have neither the necessary epistemological understandings (see Section 2) nor teaching strategies that take this broader, more encompassing view? Could the production of network models of knowledge provide a better basis for responding effectively to a complex issue that involves, but extends well beyond, science, to encompass personal religious beliefs and values?

Thinking in terms of knowledge networks seems encouraging because it could provide a means of addressing the particularly stubborn NOS misconception about the status of scientific theories. Dagher et al. found that students tend to place a high emphasis on the empirical dimension of theories that claim to be “scientific”. If a theory cannot be substantiated with direct evidence, its status as theory is questioned (Dagher et al. 2004). This is precisely the itch that intelligent design advocates seek to scratch, for evolution unfolds slowly in most instances, and evidence must be interpreted rather than read directly from a Baconian world. Dagher et al. recommend that, while the emphasis on empirical aspects of inquiry should not be abandoned, there is a need for “better treatment of the other dimensions of theories such as their logical content, historical context, and social development” (Dagher et
This call clearly resonates with Ziman’s idea of meta-science and Latour’s call for a more “realistic rendering” of how science acts in the world (Section 3).

When I began experimenting with ways to do this I was mindful that ideas about evolution are not unitary and fixed, as might be read into Haden’s response. But neither are they “anything goes”. Edmund Ruse (1999), for example, explores ways that ideas about evolution have changed and grown more complex over time, and illustrates ways these theories have reflected the values of scientists and their societies at the time. Meanwhile, the overarching idea of evolution has itself become a “reality” that informs many branches of biological research. Without it there would be no contemporary biology curriculum (another point that failed to pass the sound bite test for Campbell Live). Furthermore, theories such as “natural selection” and “survival of the fittest” have extended well beyond biology—into market theories of the economy for instance. In some instances Darwinian ideas of classical liberal economics have reintegrated with the biological sciences to produce particular theoretical approaches to scientific studies, for example of the primates (Haraway 1989, 1991).

At the broadest levels of philosophy, Darwin’s ideas may be seen as creating a powerful break from the historical dominance, since Plato, of metaphysical thought, opening up the space for philosophical positions that assume a physical rather than transcendent basis for knowledge (Davis 2004). Paul Thagard (1992) identifies Darwin’s theory of evolution as one of just a handful of “conceptual revolutions” in the history of Western science. (Others are Copernicus’ theory of the solar system, Lavoisier’s identification of oxygen, not phlogiston, as the active entity in certain types of chemical change, Newtonian mechanics, Einstein’s theory of relativity, quantum theory, and plate tectonics.) Thagard describes how Darwin’s ideas triggered a “branch jumping” revolution, which moved humans, from being ontologically quite different to animals, into being a type of animal. The “truth” stakes could hardly be higher and it is no wonder responses are often very emotional, on both sides of the argument.

With these high stakes in mind, I now suggest a less confrontational approach to addressing the epistemological status of intelligent design than is usually advocated.
by biology teachers of my acquaintance. I wanted to see if I could draw networks that compared the different ways evolution and intelligent design are embedded into the lived world of human experience. This is an ontological question in both senses of that term (“thingified” reality vs. being) and I began first with reality networks. Instead of starting with an idea in the centre, I began with something concrete from the natural world. I chose birds, partly because their biology interests me, and because the conservation of our many endangered species is an important topic in New Zealand’s science curriculum. I was also mindful that at least five of my thesis participants have an intense interest in birds and their conservation. This is a topic that they would enjoy exploring with students and I anticipate that any networks they and their students created would again be starting points, leading to the development of more conventional content, as appropriate.

To begin these networks I added five starting points that I thought would provide fruitful links for both approaches. I then proceeded to build my personal networks as before. The results are shown as Figures 10 and 11. Again, these sketches are not intended to be exhaustive, but rather to illustrate what might be produced. I realised belatedly I had left out historical contexts entirely, despite reporting research that recommends their inclusion (Dagher et al. 2004). Yet I can easily imagine Sarah, for instance, taking the history of ideas about evolution as her starting point (see Section 5).

I do realise I am unlikely to have done justice to the richness of connections that might be made by a supporter of intelligent design. For me, with my “scientific” perspective, all the more theoretical leads within the ID network took me back to a designer’s intentions, whereas the scientific theories and investigative approaches to evolution escaped in the wider world to become deeply embedded in human affairs (and in our culpability for the current state of the planet). It may well be that a supporter of intelligent design would introduce and argue a much stronger ethical perspective. Mine, I realised, had to be bracketed, because for some people science is “objective” and hence not concerned with ethics per se. The pedagogy potentially makes a space for this type of discussion, thereby meeting Symington and Tytler’s call to give “increasing recognition” to such complexities.
Figure 10 A network exploration of links between ideas about birds (from the perspective of evolutionary theory) and contemporary "matters of concern"
Figure 11 A network exploration of links between ideas about birds (from the perspective of intelligent design) and contemporary “matters of concern”
While the comparative network diagrams such as those just modeled make space for a more respectful juxtaposition of scientific and religious thinking about evolution, I think there is still a need to address questions of the appropriateness of each perspective in different situations. Without that next step, the accusation that this type of approach would simply expose students to the dangers of relativist thinking could be made. Addressing this issue, I now turn back to the results of Davis’s (2004) bifurcation research. The table below summarises the broad classification of knowledge at which he arrived.

<table>
<thead>
<tr>
<th>Nature of the universe</th>
<th>Source of knowledge</th>
<th>Means by which we come to know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metaphysical</td>
<td>Gnosis</td>
<td>Mysticism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Religion</td>
</tr>
<tr>
<td></td>
<td>Episteme</td>
<td>Rationalism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Empiricism</td>
</tr>
<tr>
<td>Physical</td>
<td>Intersubjectivity</td>
<td>Structuralism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Post-structuralism</td>
</tr>
<tr>
<td></td>
<td>Interobjectivity</td>
<td>Complexity science</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep ecology</td>
</tr>
</tbody>
</table>

What particularly interests me in the context of the exploration above is that both traditional science (as empiricism and rationalism) and religion are fellow-travellers on the metaphysical side of the knowledge divide. As I noted in Section 6, both are strong ontologies that appeal to an external authority. In the case of science that authority is the “objectivity” of knowledge built by the investigative methods of science. In the case of religious thinking an ethical authority is more likely to be overt. However, in Section 6 I also argued that weaker ontologies, as outlined by White (2000), might resonate with teachers’ passionate concerns, thereby creating a different type of space in which NOS might be introduced into the curriculum. The shift, in terms of Davis’s schema above, would be to the interobjectivity bifurcations on the physical side of the divide. From this perspective all types of knowledge systems are jumbled up in an interacting complexity, but what happens in the actual world provides a measure of the “truth” of the interpretations made. Here, potentially, science and ethics can come to be closely intertwined, with or without religious beliefs.
My final experiment was to create a network of ideas about evolution from an interobjectivity perspective. To help me get started I chose to draw on a work of science fiction. I was mindful of calls for its use in future-focused science education programmes (Section 3) but also aware that some novelists are very skilled at setting aside normally tacit ontologies to consciously rethink possible worlds. My favourite novels that explore aspects of evolution include *Lighthousekeeping* (Winterson 2004) and *Oryx and Crake* (Atwood 2003). Choosing the latter, I set myself the challenge of building a new type of network, in less than one hour, based on links to evolution I could pursue on the internet with “Oryx and Crake” and “evolution” at the centre. Figure 12 is the result, and I needed go no further than three of the first four links made by Google’s search engine (one link was slow to open so I moved on). One of these links was an interview with Margaret Atwood, the other two were wide-ranging review essays about the book.

While I rearranged the final product slightly once I had built my network, this rich set of connections was very quickly assembled and could provide the springboard for all sorts of interesting classroom discussion. The science/technology ideas are in square boxes. Fictional events and characters from the novel are in boxes with curved edges. Big philosophical questions and ethical issues are in the “cloud boxes” at the edges. It is interesting to note how easily science and religion segue together in the analyses of this novel. “Being” assumes a very important role here, bringing the second meaning of ontology into a close relationship with the “reality” meaning from science itself.

It is interesting that Davis noted that some aspects of interobjectivity thinking seemed to circle back to link with mystical perspectives (Davis 2004). Here are interesting prospects for transcending the metaphysical power struggle between traditional religions and traditional science. Since Davis describes the bifurcation between the metaphysical and the physical as a consequence of the Darwinian revolution, this power struggle is now at least two centuries behind the cutting edge of ontological debate!
Figure 12 A network exploration of links between evolutionary theory, themes from the novel *Oryx and Crake*, and contemporary "matters of concern"
Where to next?

In this section I have presented four quite different ways of building ontological networks that link science ways of representing and investigating the world to other human interests and concerns:

1. beginning with a socio-scientific issue to explore its impacts in the world;
2. beginning with a focus on empirical challenges for investigating real science issues and questions;
3. beginning with objects and “things” to explore how they are represented in different knowledge systems, including science; and
4. beginning with a work of fiction to explore how science comes together with other knowledge systems to address profound questions of “being” in our world.

While I accept that my general knowledge might be somewhat wider and deeper than that of many school students, none of these approaches to network building was difficult once I got started. The use of mapping software made making changes a simple matter, provided a means for quickly differentiating different types of entries, and allowed for revising and adding to links as I went.

Comparative networks such as those I have sketched here could be used to explore the ways different cultures understand and explain aspects of the natural world. This has been a thorny issue for science education for some time. Traditional NOS approaches require students make “border-crossings” (Aikenhead 1996) where, in effect, they meet science on science’s terms and leave their own culture behind. Section 3 noted that there have already been calls for network approaches to be used to address this issue (Gaskell 2003), without any practical means of doing so being suggested. Here, I suggest, is one practical means. Comparative networks could be drawn for any chosen object or idea, and the relative contributions of their insights to the lived world of human experience respectfully discussed.

The complementary inquiry tool of bifurcation potentially adds a powerful new ontological dimension to any such investigation. What are the purposes and
partialities that underpin different knowledge systems? Investigating this question requires more disciplined thinking than is needed to draw networks of associations. But it certainly potentially counters any accusation of “anything goes” relativism and lack of intellectual rigour in these types of pedagogical approaches. Curriculum support materials would certainly be needed to model this approach. Such materials could also include narrative stories of the “chains of transformation” that happen during scientific investigations (see Section 3).

As Section 6 showed, the production of DNA may wow students, but its success rests on an ontological reversal. For the drama to work, DNA cannot be other than a real thing. From the point of view of an epistemological NOS this “thingified” nature of science entities is naïve and problematic (Desautels & Larochelle 1998) but in reality DNA is typically talked about in this thingified way in daily life. The world became a different place from the day DNA’s structure was announced and there has been no going back. What if, taking the ontological approaches modelled in this section, we put DNA in the centre and draw a network much like those that put birds in the centre? After all, DNA is likely to seem just as real as birds to today’s students! This type of network exploration could help them see how, for example, DNA now constructs reality in the health issues we face. Adding historical dimensions to a network would bring this sharply into focus. With this type of activity added to teaching, teachers can continue to enjoy the drama of producing “things” that actually are science theories, but they can also explore ways these ideas shape the reality of the world. That is, meta-science issues could be explored for their own sake while at the same time ameliorating potentially misleading NOS messages in conventional and much enjoyed teaching demonstrations.

I think enthusiastic science teachers would be able to readily adapt the network approaches I have explored, if they were convinced of their merits. I see this as one possible way to open up a space for introducing NOS into the curriculum—something that has, to date, proved elusive. The use of bifurcation could follow at some later date. Doubtless other solutions are feasible and I look forward to seeing how teachers themselves might adopt and adapt my ideas. However, none of this will ever happen while teachers remain unconvincing of any need to change the status quo.
And so in the final section I turn to the question of NOS in relation to certain aspects of the wider organisation of schools and education systems that tend, fractal-like, to perpetuate themselves and absorb change. How might this coherence be disrupted, so that change comes to be seen as both necessary and possible?
8. What next? A reality check on NOS change possibilities

There is a significant gap between the theories of practice taught by former practitioners, based on how they would like to have practiced, and the activities performed by current practitioners. (Eraut 2003, p.60)

Introduction

Earlier I noted that most of the people known to me personally who have an interest in seeing NOS introduced to the school curriculum are no longer secondary school teachers, even if they once were. There is a warning here. For the ideas outlined in Section 7 to work, school teachers would need to want to access them and at the same time to see how to apply them in their classrooms, within the context of the wider pressures that are brought to bear on their work. It is a much-cited cornerstone of the literature on constructivist learning theories that new knowledge must be seen to be fruitful, plausible, and intelligible to the learner (Posner et al. 1982). Sections 2 and 3 argued that an epistemologically-focused NOS is unlikely to meet these conditions, and that this helps account for its non-uptake in classrooms. Might we cautiously expect a more explicitly ontological approach to NOS teaching would fare any better? This section explores aspects of the wider contexts of teachers’ work that could impact on the meaning they make from teaching approaches such as that outlined in Section 7.

Classrooms as social settings where knowledge and learning are co-constructed

To be taken up by teachers, any curriculum innovation must be able to account for the ways “science” is co-constructed in teacher—student interactions in classrooms, and for the other factors that most overtly govern teachers’ days and their work—their “being” in the classroom. The challenge of interesting individual teachers in new ideas is not enough. If it was, then Sections 5 and 6 suggest that making NOS changes might simply be a matter of supporting teachers to follow their strong personal passion for certain aspects of science that they know deeply and really care about. However the analysis in Section 5 showed that these teachers drew a strong
distinction between their personal learning and what and how they believed their students needed to learn.

Section 2 discussed this issue in the context of previous NOS reform efforts. Even where NOS ideas have been added to official curricula, they have tended to be ignored because other “message systems” of school (Bernstein 1971) such as traditional views of learning, aligned with traditional assessment practices, have hindered any possibility that the changes would be seen as either plausible or fruitful. As Section 7 showed, epistemological changes could be read as *additions* that moved beyond the scope of existing curricula, rendering the innovations vulnerable to being ignored. On this score an ontological approach to NOS would certainly prove even more challenging, if not ignorable, because there are profound implications for the way curriculum content would need to be selected and sequenced.

Nor is this innovation something that would need to make sense only to teachers. Students, too, would need to see value in what they were learning, as would their parents and those who hold teachers accountable for their work. As far as students’ learning is concerned, the possibilities for an ontologically-focused NOS do seem promising. As Section 2 noted, some previous NOS reform efforts have attempted to bring a wider relevance to the science learning of all students. I see this as a demonstrable strength of the types of learning activities explored in Section 7, deeply embedded as they are in the affairs of the world. However this assumes that relevance will not only engage students but will also be seen by them as meeting their learning needs, as they, their parents, and their teachers envisage these.

In other research projects, I have noticed how strongly both teachers and students (but especially teachers) link the phrase “learning needs” to passing examinations and gaining qualifications (see, for example, Hipkins et al. 2005). At least tacitly, topping up knowledge to pass formal examinations, along with passing other assessments that count for qualifications, is often seen as the main purpose of subject learning. The following analysis of comments made by my participants about the wider contexts of their work illustrates the pressures that help construct this narrow view of purposes for learning, even when teachers’ deepest hopes for their students’ learning are of a different type entirely.
Accountability pressures

In New Zealand, as elsewhere, there has been “an unprecedented growth in educational assessment of all kinds in the decade or so leading up to 1993” (Broadfoot & Black 2004, p.7). Patricia Broadfoot and Paul Black’s review suggests the rapid proliferation of computer storage and processing capabilities has contributed to a rise in emphasis on assessment and accountability across all walks of society, not just in education. While we have avoided a national testing regime, New Zealand has recently introduced a planning and reporting framework that requires schools to monitor and report their students’ learning against school-specific goals. Team leaders and faculty heads are held accountable for gathering the data that principals and boards of trustees will then report to the Ministry of Education. Although the policy initiative is intended to enhance learning opportunities for currently lower-achieving students, survey research has shown there is cynicism in the secondary sector about who actually benefits from the exercise (Hipkins & Hodgen 2004).

Charged with this new responsibility, Sarah found herself torn between providing data she could believe in and a purpose that she did not support:

So we did a pre-test and then we did a post-test [of a unit of work] because my feeling was that when initiatives are brought in, and if the Ministry are behind them, they want figures and facts. And to say it is holistic, well you need some benchmarks. And I have been in the system too long and just know that they want something they can pin it onto. So how do you know? You want something that is accountable. So that is what we came up with, with what information I had about what was required of it. But I am not happy. I am not happy with it all. (Sarah, Interview 4)

Pre- and post-testing is the most common interpretation of “formative assessment” made by secondary science teachers in New Zealand (McGee et al. 2003) so Sarah is not alone in her interpretation of the type of “evidence” of effective teaching she was required to produce. Her reasoning, like that of most science teachers, is located in a realist ontology that privileges a certain type of empirical data. It is not difficult to see how the perception of an obligation to provide such data would constrain the science produced in the classroom to settled “facts” that can be judged right or wrong in their recall and application.

With its inherent uncertainties, an epistemologically-focused account of NOS could not fit comfortably into the taught curriculum in these circumstances. Whether a
more explicitly ontological account of NOS could fare any better now becomes an important question. Encouragingly, Sarah acknowledged that a more holistic interpretation of the success of learning might be intended by the planning and reporting framework. This suggests a chink of possibility for helping her to reinterpret the meaning of “evidence of learning”, especially in view of her wider goals for students to become environmentally responsible citizens. As Davis (2004) points out, complexity orientations to knowledge define ethical action not as a set of principles that could be written about (e.g. in a conventional examination or test) but rather as contextually appropriate behaviour. In this view, what students do in the world is the ultimate form of accountability for their learning. It is not difficult to see that this would match well to my participants’ passions, as outlined in Sections 5 and 6, if the education system legitimated this approach. As I outline next, I do not see assessment as an issue that individual teachers can solve on their own.

“Marketisation” and teacher identity

Even when individual teachers hold a different view of the purposes of learning science, they can be vulnerable to accountability pressures within the school. On her return to school Alice was disturbed by an apparent change in educational priorities, under the leadership of a new, younger male HOD:

I guess the aim down there is to try and get kids through exams so you are better with the net comparison between schools, and comparison between teachers. (Alice, Interview 3)

Throughout her career, Alice had invested heavily in being the sort of teacher who wanted to make a difference, especially in terms of environmental issues and the like:

Teaching isn’t just teaching. Teaching is education. So I think I saw that when I first went into teaching in terms of—and then looking at these environmental issues and recognising that there was value and we had to define that value in the resources that we had and we used for biology teaching. And it wasn’t just for teaching. It was in terms of an education. (Alice, Interview 1)

The ideals being expressed here are familiar. I would have said much the same about my reasons for becoming a biology teacher. Like me, several of the participants in my study were nearing retirement age and began their careers in the early 1970s—a time that Basil Bernstein (2000) described as an unusual and brief-lived time of liberal thinking in education, with an associated opening up of educational
opportunity. For older teachers, a previously comfortable match between personal ideals and a certain type of teacher identity may have been disrupted by more accountability-focused systems.

John Beck and Michael Young (2005) provide a thoughtful analysis of Bernstein’s contribution to the understanding of the identity challenges that professionals face in an era of increased accountability, when the autonomy of the academic disciplines is being eroded by forces such as increasing marketisation of education. Of particular interest to a deeper understanding of the dilemma faced by both Alice and Sarah, they discuss the manner in which Bernstein linked “inner dedication” as a professional to the development of particular types of professional autonomy. Such autonomy includes control over conditions of work, control over the boundaries of the relevant knowledge base within the academic discipline, ethical responsibility, and socialisation into the values and standards of the professional community.

In various ways these aspects of autonomy have been challenged by trends to marketisation and increasing accountability pressures with the consequence that:

> Those who have felt most traumatized and hostile to marketization and the extension of external regulation are mainly professionals who enjoyed high levels of autonomy at earlier stages of their careers. (Beck & Young 2005, p.194)

Beck and Young point out that younger professionals may have experienced training that led them to shape different ambitions, expectations, and ideas of what might be strategic for career success. Specifically, they said these might be based on “more instrumental assumptions” (p. 194) than those held by older professionals. In the case of teaching, such assumptions could well include a focus on success in accountability-focused assessments as the most important outcome to be achieved. Again, the question becomes how to address NOS in ways that can either fit with or realign the assessment/accountability agenda, since this is unlikely to change, at least in the short to medium term. Addressing this challenge, I want to first propose a temporary accommodation, and then move on to a more radical rethinking of educational priorities.

If the construction of network diagrams, as explored in Section 7, were to open up new ways of keeping traditional conceptual learning closer to the real-world contexts
of interest and concern to students, then at least the traditional component of their learning could continue to be assessed by traditional means. This is the temporary accommodation I envisage to meet the challenges posed by the accountability agenda. However it brings both benefits and risks. The benefits concern continuity and manageability in a time of relentless educational change. The risks are “business as usual”, with the new focus being seen as an interesting and motivating add-on, but not really integral or pivotal to rethinking ways students should and can relate to science knowledge at work in the world. For the more far-reaching ontological goal to be achieved, views of teaching and of assessment would need to be realigned to the new types of ontological orientation sketched in Sections 3, 4, 6, and 7.

This, clearly, is a challenge that would take time to address. Assessment and accountability issues originate at the systems level, not with the thinking of individual teachers, although individuals are likely to implicitly uphold hegemonic practice (Apple 2004). Thus, changes would need to be put in place at the systems level, not just in individual classrooms. Painting a clearer picture of what an ontological rethinking of curriculum and assessment practices could look like, at least in principle, might be a first step in this direction.

**Images of teaching from an inter-objectivity perspective**

Teaching participates in the invention and reinvention of itself. Unlike many of the forms that contribute to the structures of our existences, teaching has a say in what it becomes. (Davis 2004, p.184)

For teachers to have a say in what teaching becomes, they need to be aware of new possibilities. Davis identifies several aspects of professional structures that would need to be rethought for metaphors of teaching based in inter-objectivity models of reality to become more widely established. I next consider these in turn.

As already noted, Davis suggests that pre-specified learning objectives and formal lesson plans need to be reframed in terms of “liberating constraints”. These are “guidelines and limitations for activity that are intended to provide enough organization to orient students’ actions while allowing sufficient openness for expression of the varieties of experience, ability and interest represented in any social
grouping” (p.169). I believe that the network diagrams and bifurcation analyses modelled in Section 7 meet this challenge at the classroom level. They are not “anything goes” but nor are they “content as usual”. And the network diagrams do make a space for students’ interests and concerns to be introduced at the outset of a unit of work, so they help determine the learning direction for what follows.

Following on from this, Davis suggests reframing views of the whole class as a collective learner rather than collection of individual and isolated learners. Such a class could be seen to have the properties of a self-organising, learning, evolving entity, of the sort envisaged in complex systems theory. Taking cues from the systems theory literature, the likelihood of effective learning emerging in such a class would be maximised when two key conditions are met. First there would need to be a sufficient diversity of ideas introduced for joint exploration. Second, the foundations for that exploration would need to be grounded in sufficient redundancy—that is, the class would need to have access to sufficient common ground within which to meaningfully interact with the diversity of ideas presented. Again, I believe the approach modelled in Section 7 could meet these challenges. Students’ individual perspectives, cultural values, and beliefs would bring diversity, while the common structure of the approach and the concepts of science—the “beating heart” of Latour’s networks and links (Section 3)—would bring the redundancy.

Davis further suggests that once these shifts had been made, lesson plans could be reframed as “thought experiments rather than itineraries or trajectories—as exercises in anticipation, not prespecification” (p.182). Davis appears to be optimistic that such changes can be achieved, especially if we develop a new vocabulary for talking about teaching from this perspective. This is intellectual work to which many of us with an interest in science education would need to contribute. It clearly cannot be left to teachers alone, although obviously neither can change happen without their active support. What might it take to get such conversations underway?

**Supporting transformative change in teaching**

Exploring adult education as a democracy-strengthening process, Stephen Brookfield (2005) reviews the theories of Jurgen Habermas to propose that it is necessary for learners to find a way to look outside their own “lifeworld” perspectives. It seems to
me that this is exactly what all of us with an interest in science education need to be able to do when thinking about matters such as the introduction of NOS into the curriculum. Time per se will not do the trick. Nor will direct experiences of working science per se, as has been suggested in the past (Section 2). My participants had a whole year, admittedly busy with science projects, in which they might have looked back in on their teaching lifeworld. That they did achieve some distance from this world was evident when they talked about what they saw through “new eyes” when they went back to school. However these comments tended to be about the need to resist busy work, not about profound changes in teaching practice.

Brookfield (2005) suggests change is not easy to achieve because the lifeworld “exists prereflectively, inside consciousness” (p.1140). Its familiarities and tacit assumptions are taken for granted. He suggests that “segments of the lifeworld can be glimpsed when they are thrown into sharp relief as situations we have to respond to” (p.1140). He recommends creating spaces for supported conversations, away from the pressures of the usual work environment, where issues can be debated and challenges to habitual thought patterns confronted. If the enclosing circle of tacit lifeworld views can be breached, new worldviews that are already “latently available” (p.1149) may be brought to full consciousness and used as the basis for transforming actions.

The deepest thoughts of my participants suggest the necessary understandings for the type of NOS transformation I propose are indeed latently available. As outlined in Sections 5 and 6, teachers’ avid personal interests in science and in the natural world have the potential to provide the latent, potentially transformative, worldviews envisaged by Brookfield and Habermas. In the press of day-to-day survival teachers’ “cover stories” appear to keep them safely at bay (see Section 5) so they need a space where all their beliefs and passions can be brought into view and explored. Better yet might be the provision of such opportunities before teachers became so bound up in traditional practices—that is, if they were provided with a safe space to radically rethink their views of science and science teaching as part of their pre-service teacher education. This shifts some of the reframing challenge from classroom teachers to teacher educators and other tertiary science teachers.
Within a science education pre-service course, or indeed in in-service courses, the types of network drawings I have sketched above could be readily produced in relation to teachers’ science interests and perhaps to science projects undertaken to build their familiarity with the complexities and uncertainties of scientific inquiry undertaken to investigate actual problems such as scientists might investigate. These combined experiences could be used as one avenue for unsettling tacitly held strong ontologies, encouraging teachers to follow their passions in exploring matters of concern, not just matters of fact. Diversity (in their viewpoints) and redundancy (in their shared commitments to science and the natural world, and shared purpose as teachers of science) could allow for new insights to emerge. At the very least, a different type of conversation about teaching would have been started.

In conjunction with these teaching changes, curriculum changes would also be needed. In New Zealand there has been a recent move to encourage greater use of school-based curriculum design (Bolstad 2005) and greater assessment flexibility (Hipkins et al. 2004). Such developments present new opportunities for change—if these are recognised and taken up. To encourage this possibility, new resources would need to be developed to provide rich stories to support exploration of the matters of concern that are likely to be raised. As Lemke has pointed out, and science educators like Ryder have demonstrated empirically (Section 7), it is possible to identify likely common themes and principles, and so anticipate to some extent topics for support materials that could lead the way. The time seems to be right, if we can muster the necessary courage and conviction.

**In conclusion**

In this thesis I have provided evidence that all eight of my participants were passionate people—engaged with science and the natural world most certainly, but also with students and learning. They took their ethical responsibilities seriously and wanted to resist what they saw as unhelpful developments in schools. I am hopeful that change in their practice to permit better NOS exploration is both possible and something that they would embrace, in the following circumstances:

- Teachers have the space to explore the nature of knowledge—a participatory epistemology requires participation—so that they come to see knowledge as problematic, rather than as a given. Narrative resources could help here,
• providing opportunities to examine matters of concern from different ontological perspectives.
• Relativism as a response to the unsettling of strongly realist ontologies is explicitly resisted and network alternatives are modeled and explored.
• These alternatives point to easily implemented learning strategies (as in the network drawings), with readily available supporting resources, especially in narrative forms.
• Teachers also have space and time to explore the nature of learning, curriculum, and schooling traditions.
• Wider changes complement and support rather than undermine changes they wish to make in their classroom practice (e.g. assessment and accountability “messages” align well with any reforms).

All of this takes the NOS issue far from teachers’ perceived epistemological deficits with which the thesis began. I am not confident that change will be easy—that would be to deny the scale and scope of the above conditions. However, true to the complexity orientation of the thesis, I propose we simply make a start, in the hope that we can find a “tipping point”. An extensive literature suggests that traditional NOS education and professional development has not generated change, and by my analysis, will not succeed in doing so. Meanwhile, as Section 3 outlined, changes to the nature of knowledge in the wider world are continuing apace, making conditions for schooling more difficult and complex. Adding ontology to the curriculum mix may help teachers better understand these changes, even as it suggests more manageable, meaningful, and exciting ways to address the issue of NOS in the curriculum.
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Appendix 1: Request for access to research participants

22 The Crescent
Raumati South

23.11.2002

Steve Thompson
Chief Executive
The Royal Society
Box 528
Wellington

Dear Steve

Some time ago we had a telephone conversation about the Teacher Fellowships as a possible focus for my PhD research. I have now worked through the issues of designing a means of gathering data to seek answers to the questions I have posed. My supervisors, Drs Jane Gilbert and Geraldine McDonald, are happy with my plans and my research questions have finally been approved by Victoria University’s ethics committee.

When we spoke, you indicated that you would be very happy for the research to proceed, and you asked to be kept suitably informed. I undertook to forward you copies of the participant information and other relevant research protocols. A copy of these materials is included with this letter.

I trust that the information provided satisfactorily meets your request to be informed of my progress. I am looking forward to working with a group of the 2003 science teacher fellows, and trust that I will be able to make the experience as stimulating and thought provoking for them as I am sure it will be for me.

As I indicated when we spoke, I will provide reports of my progress from time to time, and a copy of the completed thesis. I hope also to be able to present the preliminary findings at the NZASE conference in 2004. Thank you for supporting my plans.

Yours sincerely

Rosemary Hipkins
Appendix 2: VUW participant information and consent forms

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wananga o te Upoko o te Ika a Maui

Participant information sheet

An exploration of possibilities for achieving change in school science teaching

Information for research participants

- Participation in this research is completely voluntary and is confidential.
- Agreement to take part is in no way linked to your acceptance of the 2003 Royal Society Teacher Fellowship.
- No one at the Royal Society will be aware that you are a research participant unless you choose to say so.

The intent of the research

I am interested in the nature of science (NOS), and links between teachers’ NOS views and their classroom science teaching. Some researchers attribute the persistence of certain types of NOS views to the limited opportunities teachers have had to experience actual scientific research. Since teachers who are awarded a Royal Society Fellowship in science will have just such opportunities during their fellowship year I would like to investigate how, and under what conditions, the experiences do/do not lead to change in nature of science views and/or classroom teaching practice.

What will be involved

Teacher fellows who agree to participate in the research will be involved in four individual interviews. Each interview will probably take between 40 minutes and one hour. Most will be by telephone, although face-to-face settings will be used where possible.

The initial interview will take place soon after the whole group first meets in Wellington at the end of the 2002 year. Topics explored will relate to current views of the nature of science and science teaching.
Midway through the fellowship in the 2003 year, the second interview will explore thoughts about scientific knowledge building in real research settings, as contrasted with school learning.

At the end of the fellowship year, we will discuss the overall experiences of the fellowship year and plans for the following year, especially for future science teaching. Midway through the 2004 year we will have a final discussion about how things have worked out back in the classroom, especially how the experiences of the fellowship year have impacted on actual teaching practice.

**Benefits of participation**

I will aim to provide conditions for thought provoking dialogue to make the experience stimulating and enjoyable.

**Communication of the findings**

In the first instance, the findings will be written up as my PhD thesis. I will also prepare a report for the Royal Society that outlines the major findings of the research. I hope to be able to develop conference papers and articles for science education research journals, as appropriate, as the research proceeds.

**How privacy will be protected**

Each participant will be asked to select a pseudonym by which they will be known throughout the duration of the project. No contextual details that could lead to the identification of an individual will be included in any published data. (Such details could include specific geographic location, exact nature of fellowship research project, school at which participant teaches, and any specific national or local role in science education that could lead to identification.)

I will use the chosen pseudonym to make notes during telephone conversations so that I will be the only person who knows the real identity of the person being interviewed in each case. I will tape each conversation, but the real identity of the interviewee will not be revealed to the person who transcribes the data, or to my thesis supervisors who may wish to read the transcripts. The interview sheets and tapes will be kept in a locked filing cabinet in my work office. Electronic files on my computer are protected by password only access. Two years after my thesis has been deposited in the University Library the tapes will be wiped and the transcripts and notes will be shredded.
If after reading this you would like to participate in this project, please complete the consent form attached and post it to me in the envelope provided. Thank you.

Rosemary Hipkins
New Zealand Council for Educational Research
Box 3237
Wellington
Phone: 04 802 1465 (work)
E mail: rose.hipkins@nzcer.org.nz

Supervisors’ contact details:
Dr Jane Gilbert Dr Geraldine McDonald
Victoria University Victoria University
Box 600 Box 600
Wellington Wellington
An exploration of possibilities for achieving change in school science teaching

Research Consent Form

I would like to be a participant in this research project.

I have read and understand the purpose of the research, the commitment I will be making, and the conditions under which the research will be carried out.

I am happy for data generated by interviews with me to be shaped into research papers and/or conference talks and/or reports for the Royal Society, under the conditions of confirmation and confidentiality specified.

I understand that I can withdraw from this project at any stage before the final analysis of the data.

I understand that if I withdraw from the project, any data I have provided will be destroyed.

I understand that any information or opinions I provide will be kept confidential and reported only in an aggregated/non-attributable form.

I understand that the information I have provided will be used only for this research project and that any further use will require my written consent.

I understand that when this research is completed the information obtained will be destroyed.

Name:

Signature:

Date:
Dear [name]

I am writing this letter to provide you with a revised plain language statement about my research project: An exploration of possibilities for achieving change in school science teaching. This may strike you as unusual, in that you have already signed the consent form I prepared when I was enrolled at Victoria University of Wellington. As I indicated in my letter with the returned first transcripts, I have withdrawn from VUW. Now that my enrolment at Deakin University in Melbourne has been completed, I am almost in a position to pick up the interview process where we left off. However there are some small differences in the ethics requirements of the two institutions and so I need to seek your consent afresh before we can begin the second round of interviews. Could you please read through the following information, make sure you are still happy with the conditions outlined, and then sign and return the consent form to me in the enclosed pre-paid envelope. Thank you.

Introduction to the research

This research project is being completed by me (Rosemary Hipkins) in my role as a part-time PhD student at Deakin University. The findings of my research will be used for my PhD thesis. I will also prepare a report for the Royal Society that outlines the major findings of the research. I hope to be able to develop conference papers and articles for science education research journals, as appropriate, as the research proceeds. My new supervisors are Associate Professors Noel Gough and Russell Tytler. Their contact details can be found at the end of this letter.

Aims of the project

I am interested in the nature of science (NOS), and links between teachers’ NOS views and their classroom science teaching. Some researchers attribute the persistence of certain types of NOS views to the limited opportunities teachers have had to experience actual scientific research. Since you have been awarded a Royal Society Fellowship in science you are now experiencing such opportunities during your fellowship year. My aim is to investigate how, and under what conditions, these experiences do/do not lead to change in nature of science views and/or classroom teaching practice when you return to your school (if you do).

What is involved

We have already completed the first of the four planned interviews, so you are aware of the types of semi-structured questions I have planned, and that the interviews take between 30 and 40 minutes each, and that I am taping these and making a full transcription of each conversation.
However I do now need to modify the time frame proposed when you originally agreed to the research. The process of changing institutions has taken some time and the second interviews are already delayed so I thought it wisest to readjust the third and fourth interviews too. Please check the proposed new timelines below to ensure that these time frames are still suitable. (I am happy to negotiate small changes if need be.)

Original time for second interview: July 2003
Proposed new time: late August-September 2003

Original time for third interview: December 2003
Proposed new time: late February-March 2004

Original time for fourth interview: July 2004
Proposed new time: August-September 2004

Privacy issues
Throughout the duration of the project I will continue to use the pseudonym by which you are known—when making interview notes and transcribing the tapes, as well as when quoting from them. The consent form which includes both your name and your pseudonym is kept in a separate location from the completed transcripts, interview notes, and tapes.

The small excerpts of the first interviews that I collated illustrate how your privacy is protected by careful elimination of contextual details that could lead to identification. Such details include specific geographic location, exact nature of fellowship research project, school at which you teach, and any specific national or local role in science education that you may happen to discuss in our interviews. As you will be aware, many of these details have been edited out as I have transcribed the tapes of our first interviews. (Details of your project are an exception to this because they set a context for many of the other comments you made and so I need to keep them in for now but I will not cite them.)

I will continue to tape each conversation, and have decided that I need to transcribe all the tapes myself. For each of you individually, no one expect me, you, and my thesis supervisors will see these transcripts. The interview sheets and tapes are being kept in a locked filing cabinet in my home office. Electronic files on my computers at work and at home are protected by password only access. Six years after my research has been completed the tapes will be wiped and the transcripts and notes will be shredded.
**Continuing consent**
As you know, you are able to have any excerpt that you are not happy with removed or modified in any transcript. (Some of you have already returned the first transcripts with some small modifications.) You can withdraw from this project at any stage before the final analysis of the data and if you choose to do so any data you have provided will not be used and will be destroyed.

**Sharing the results**
I will provide you with a copy of the report that I will ultimately prepare for the Royal Society and with a summary of my thesis findings. From time to time, I may share edited short sequences from the transcripts, as many of you requested after the first interview round in response to several of the questions asked.

Contact details for further information or questions about participation:

Rosemary Hipkins  
New Zealand Council for Educational Research  
Box 3237, Wellington  
Phone: 04 802 1465 (work)  
E mail: rose.hipkins@nzcer.org.nz

**Contact details for principal supervisor**
Noel Gough, Associate Professor  
School of Social & Cultural Studies in Education  
Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Australia  
61 (0)3 9244 3854 (office/voicemail), 61 (0)3 9244 6752 (fax), 0417 311 219 (mobile)  
noelg@deakin.edu.au

**Contact details for second supervisor**
Russell Tytler, Associate Professor  
School of Science & Development Studies in Education  
Faculty of Education Campus: 221 Burwood Highway, Burwood Victoria 3125, Australia  
61 03 924 46396 (office/voicemail)  
tytler@deakin.edu.au

Should you have any concerns about the conduct of this research project, please contact the Secretary, Ethics Committee, Research Services, Deakin University, 221 Burwood Highway, BURWOOD VIC 3125. Tel (03) 9251 7123 (International +61 3 9251 7123).
DEAKIN UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE
CONSENT FORM:

I, 
of

Hereby consent to be a subject of a human research study to be undertaken by Rosemary Hipkins and I understand that the purpose of the research is to explore links between teachers’ nature of science views and their classroom science teaching, and like to investigate how, and under what conditions, the experiences of a Royal Society Fellowship in Science do/do not lead to change in nature of science views and/or classroom teaching practice.

I acknowledge
1. That the aims, methods, and anticipated benefits, and possible risks/hazards of the research study, have been explained to me.

2. That I voluntarily and freely give my consent to my participation in such research study.

3. I understand that aggregated results will be used for research purposes and may be reported in scientific and academic journals.

4. Individual results will not be released to any person except at my request and on my authorisation.

5. That I am free to withdraw my consent at any time during the study, in which event my participation in the research study will immediately cease and any information obtained from me will not be used.

Signature: Date:
Appendix 3: Data gathered from fellowship application forms

1. Gender:
   a. M
   b. F

2. Age:
   a. 20—24
   b. 25—29
   C. 30—34
   d. 35—39
   e. 40—44
   f. 45—49
   g. 50+

3. School levels of current teaching:
   a. Years 1—6
   b. Years 7—8
   C. Years 7—13
   d. Years 9—13
   e. Years 11—13

4. Subjects currently taught
   a. All subjects (primary)
   b. Science
   c. Senior Science (Years 12/13)
   d. Biology
   e. Chemistry
   f. Physics
   g. Mathematics
   h. Earth Science
   i. Horticulture
   j. Agriculture
   k. Biotechnology
   l. Electronics
   m. Human Biology
   n. Other
5. Years of teaching experience:
   a. 1—4
   b. 5—9
   C. 10—14
   d. 15—20
   e. 20+

6. Other science-related employment:
   a. Research scientist
   b. Tertiary teacher
   c. Technician
   d. Other

7. Qualification:
   a. BEd
   b. BSc
   c. BSc(Hons)
   d. MSc
   e. PhD
   f. Other

8. Specialist discipline:
   a. None
   b. Biology
   b. Chemistry
   c. Physics
   e. Geology
   f. Astronomy
   e. Ag/Horticulture
   f. Biochemistry
   g. Electronics/computing
   h. Mathematics
   i. Nutrition or other human science
   j. Other

9. Stated aims for fellowship:
   a. to learn specific science techniques/procedures to talk about
   b. to learn specific techniques/procedures to use in practical lessons
   c. to learn new web-based skills
   d. to learn more in conceptual areas related to own science discipline
   e. to learn more in conceptual areas related to a different science discipline
   f. to investigate a question related to personal interests/hobbies
   g. to investigate a question related to hosts’ current research programme
   h. to investigate a question likely to be of interest to school pupils
   i. to contribute to a public interest project (e.g. in conservation)
j. to increase ability to talk about “real science” in the classroom
k. to learn about technological applications of new scientific research
l. to learn more about the nature of science
m. to produce specific resources
n. to make new community contacts likely to be useful in subsequent teaching
o. to have a rest/recharge
p. other
Appendix 4: The interview questions

First interview

1. Congratulations on your fellowship. Could you briefly explain the research you are going to undertake.

2. How do you think the experiences you will have on the fellowship will help your teaching?

3. What made you decide to become a science teacher? (for primary teachers: What made you decide to become a teacher?)

4. Do you think practical work is an important part of science learning for school students? (Why/why not?)

5. What kinds of practical work do you like doing with your students?

6. Have you had any opportunities to do scientific research? (Yes/no). If yes, tell me about your experiences of scientific research. If no, what sorts of research experiences do you think you will encounter during your fellowship year?

7. What is knowledge?

8. How do we get knowledge?

9. Is science knowledge different from other sorts of knowledge? Why/why not?

Second interview

Thank you for allowing me to re-interview you. Can I begin by raising a couple of things from the first interview? (A different question or short series of questions related to each participant research was posed at this point.)

Now we’ll move on to the common questions for this interview. This time, I’d like to explore your ideas about the kinds of things that scientists do when they carry out their research. I’ll begin with your experiences of your own project, and then move on to some more general questions.

1. How do the kinds of science you are experiencing this year compare with the science you were exposed to as a school student?

2. What has got you most excited/involved in your fellowship experience so far?

3. What aspects of the science you are experiencing have taken you most by surprise? Why is that?

4. Do you think experiments are an essential part of the development of scientific knowledge? Why/why not?

5. Are science and the arts similar? (Yes/no). If yes, how are they similar? If no, how are they different?
6. After scientists have developed a theory (e.g. atomic theory), can the theory change? If yes, how and why can theories change? If no, why can’t theories change?

7. Some astronomers believe the universe is expanding while others believe that it is still shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible since all these scientists are looking at the same universe?

8. Is there a difference between scientific knowledge and opinion?

I’d like to end by asking you if you had any more thoughts about the question of what knowledge is—either from just thinking about it yourself, or after you read the summary of everyone’s comments.

**Third interview**

1. You’ve just returned to school after a year of very different types of working and learning experiences. Can you tell me what you see as the main way(s) you’ve changed as a person as a result of those experiences?

2. How does it feel to be back at school? When you very first returned, did you feel as if you were looking at some aspects of your teaching job “through different eyes”?

3. Do you think your experiences last year will change the way you help your students to learn about experimental science/genetics/what’s involved in making field observations (as relevant to each person’s project) or any other aspect of scientific inquiry?

4. Can you think of any times last year when you felt particularly powerful (or powerless) as a learner? How might those types of experiences influence your science teaching?

5. What does “attitudes” in the Developing Scientific Skills and Attitudes strand of the curriculum mean to you?

6. Did you have occasion during the fellowship to reflect on, or talk about, how scientists’ personal beliefs, attitudes, and values might influence their work? (Yes/no). If yes, tell me about that. If no, do you think this is something that could influence scientists’ work?

7. What does “the nature of science” in the Making Sense of the Nature of Science and its Relationship to Technology curriculum strand mean to you?

8. Do you think the curriculum clearly explains the meaning of this strand? Why/why not?

9. Did you talk with any of the scientists you worked with about what “science” means to them and/or how it “works” in their particular field?
Fourth interview

1. Do you think your science teaching has changed since you returned to school? Tell me about that.

2. Have you used stories from your fellowship year in your classroom teaching? Tell me about those.

3. Are there any other changes you would like to make to your teaching that you feel are just not achievable at the moment? If yes, tell me about those.

4. Have you included any discussions about what science is and how it works in your teaching since you returned to school? (Yes/no). If yes, tell me about that. If no, would you have liked to?

5. In your opinion, does school science give students a realistic idea about what scientific knowledge building is really like? Why/why not?

7. Knowing what you know now, what, if anything, would you have changed to make your year a richer experience for your future teaching?