The development of science epistemology in senior science courses

A quantitative study

Edit McIntosh

Victoria University of Wellington

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"The reciprocal relationship of epistemology and science is of noteworthy kind. They are dependent upon each other. Epistemology without contact with science becomes an empty scheme. Science without epistemology is—insofar as it is thinkable at all—primitive and muddled. However, no sooner has the epistemologist, who is seeking a clear system, fought his way through to such a system, than he is inclined to interpret the thought-content of science in the sense of his system and to reject whatever does not fit into his system. The scientist, however, cannot afford to carry his striving for epistemological systematic that far. He accepts gratefully the epistemological conceptual analysis; but the external conditions, which are set for him by the facts of experience, do not permit him to let himself be too much restricted in the construction of his conceptual world by the adherence to an epistemological system. He therefore must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as realist insofar as he seeks to describe a world independent of the acts of perception; as idealist insofar as he looks upon the concepts and theories as free inventions of the human spirit (not logically derivable from what is empirically given); as positivist insofar as he considers his concepts and theories justified only to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as Platonist or Pythagorean insofar as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research. "(Einstein, 1949, pp. 683-684)

Einstein, A. (1949). Albert Einstein: philosopher-scientist (Vol. 7): Library of Living Philosophers.

Abstract

Epistemological development is a pivotal aspect of liberal education because the ability to distinguish between knowledge and pseudo-knowledge and the ability to use the particular methods of reasoning associated with various disciplinary fields equips people to make judgements in complex issues. The present study examines the extent to which studying each of the different science disciplines in secondary years 12 and 13 supports the development of science epistemology. A further aim was to determine the relationship between epistemological development in science and the completion of inquiry-type coursework. Data were collected from 735 year 12 and 13 students from 11 schools, mainly from the Wellington region. A survey, designed for this study, comprised statements about the *nature of science* and *scientific argumentation* conceptions, two pivotal aspects of science epistemology. Using a quasi-experimental design, this quantitative study explores the extent of the development of science epistemology over a year of studying science, by comparing students' scores in Term 1 with scores in Term 3 on the instrument.

The findings showed a more advanced epistemic view among science students; however, a positive effect of science studies on epistemic development was not evident. It was concluded that a greater emphasis on authentic inquiry is essential for epistemic development and, while understanding of the philosophical assumptions underpinning scientific knowledge is important, this should arise from authentic science inquiries – or the *processes* of science – rather than being taught in isolation from the practice of the discipline of science. This leads to a question the extent to which an emphasis should be placed on the ontological aspects of the philosophy and the sociology of science, potentially at the expense of developing sound understanding of science epistemology.

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Table of Contents

List of Tables

List of Figures

CHAPTER 1

Introduction

In the present study, the development of two aspects of science epistemology as a consequence of studying science - *nature of science* and *scientific argumentation* – are investigated.

The theoretical underpinning of this study is provided by a significant body of research supporting a shift in science education from a content-based syllabus to one that promotes understanding of the development and use of scientific knowledge. This pivotal aspect of science education enables students to evaluate the validity and reliability of scientific knowledge claims – and therefore to distinguish between science and pseudo-science. Furthermore, an understanding of the knowledge-generative processes and the power and limitation of scientific knowledge can support informed decision-making in socio-scientific issues in everyday life (Khishfe, 2012a). I appears, therefore, to be an aspect of science education that overarches all science disciplines and could be applied in various contexts, literally on a daily basis, in contemporary societies saturated with truth claims that are purporting to be based on scientific evidence.

The branch of philosophy that is concerned with the difference between belief and knowledge, and the processes by which science knowledge is developed is called *epistemology*. The inclusion of science epistemology in education arose from liberal educational ideals and has been a centrepiece of science education policy worldwide since the late 20th century. In the 19th century, at time of the rise of liberal education, a motivation for turning towards epistemological considerations was an intention to develop the skills of justified reasoning, and therefore to cultivate the ability to distinguish between knowledge based on evidence, from belief handed down from authority. In today's education policy the development of science epistemology is promoted by various discourses such as those of *scientific literacy*, the *citizen scientist*, *powerful knowledge* and *knowledge society*. All of these discourses are founded upon assumptions similar to those made by liberal educators in the past. An example is that informed epistemological views enable individuals to "resolve competing knowledge claims, evaluate new information and make fundamental decisions that affect their lives and the lives of others" (Hofer, 2001, p. 354)

To address various aspects of the philosophical underpinnings of scientific knowledge a collection of conceptions were bought together under the term *nature of science* (Lederman, 2007). This construct is based on over 40 years of research, and today is a widely-used concept in science curricula. While the *nature of science* construct is mostly concerned with the philosophical underpinnings and the sociology of science, it is also commonly referred to as science epistemology and is described as a scientific way of knowing, or as values and assumptions intrinsic to the advancement and justification of scientific knowledge (Deng, Chen, Tsai, & Chai, 2011; Lederman & Zeidler, 1987). Some of the philosophical assumptions about the nature of scientific knowledge, for example, whether science is concerned with knowledge relative to the knower or discovering an objective world or whether scientific theories are constructed seem to be unrelated to some of the social aspects, such as the influence of political or economic pressures on research agendas. Other tenets of *nature of science* include assumptions *about* some aspects the process of science inquiry, for example, that science knowledge is based on empirical evidence and deduction. Although there are references made to some of the process of science inquiry the *nature of science* construct is distanced for the process inquiry. Therefore, *nature of science* appears to comprise an assortment of assumptions arising from various disciplinary fields, which has led to conflicting ideas about its tenets and their meanings. While *nature of science* is often equated with science epistemology, the tenets are clearly separate from processes of *science inquiry* and the process of *scientific argumentation*.

Scientific argumentation includes conceptions about the application of scientific reasoning to the evaluation of hypotheses and of competing models and theories, taking account of the validity and the limitations of scientific evidence (Giere, 1979). Research on *scientific argumentation* in relation to epistemic development has been primarily concerned with the process of building and evaluating arguments, which has generally involved a critical "coordination of evidence and theory that supports or refutes an exploratory conclusion, model or prediction" (Duschl & Osborne, 2002, p. 44). This occurs in authentic science inquiries, including the evaluation of competing theories, and in relation to socio-scientific issues that can inform personal and political decision-making. The coordination of evidence is therefore critical to an understanding of the empirical and analytic procedures that underpin the reliability and validity of scientific investigations.

Some research has suggested that learning *scientific argumentation* has positive effects on the development of other aspects of science epistemology (Kenway & & Bullen, 2003; Sandoval

& Millwood, 2007). Furthermore, it has been asserted that the use of *scientific argumentation* during authentic science inquiry supports understanding of the scientific process for making knowledge claims (R Gott & Duggan, 2007; Roberts & Gott, 2010). These skills, in turn, can be transferred to critical analysis of scientific claims made by scientists in socio-scientific contexts. Sandoval's (2005) findings suggest that the development of *scientific argumentation* skills has a positive effect on the development of both formal epistemology– sets of ideas about knowledge production by professional scientists - and practical epistemology – students' ideas about their own knowledge generative processes during science inquiry. From all of this follows that an educational focus on *nature of science* and *scientific argumentation* are important for the development of science epistemology. The present study investigates the development of and the interplay between the conceptualisation of the *nature of science* tenets and *scientific argumentation* skills as indicators of epistemological development.

CHAPTER 2

Epistemology

The theoretical underpinnings of epistemology

Epistemology in general - and therefore science epistemology in particular - is a branch of philosophy that is concerned with aspects of knowledge and knowledge generative processes. This includes the meaning of knowing, sources of knowledge, reliability of knowledge and the scope and limitations of knowledge (Wenning, 2009). Other sources refer to science epistemology as the logical and philosophical grounds upon which scientific claims are advanced and justified (Sandoval & Millwood, 2007, p. 71) or beliefs about the ways in which knowledge is constructed and evaluated, and about the location of knowledge (whether it equated with an objective reality or assumed to be located in the minds of the knower; (Hofer, 2001).

The origins of the contemporary conception of science epistemology can be traced back to the 17th century, specifically, to Bacon's *Novum Organum* (Bacon, 1678) that formalised logical analysis. Although several philosophical paradigm shifts have occurred since then – e.g., from positivist to constructivist and realist - the basic assumptions and procedures leading to the establishment of knowledge in science have remained the same: knowledge is a justified belief that is derived from evidence and reasoning (Goldman, 1979; Hofer & Pintrich, 1997).

The main aspects of the justification of knowledge claims, and therefore, the basic tenets of human reason are: *rationalism*, *reliabilism*, *coherentisim* and *empiricisim*. Rationalism affirms that logic is a source of knowledge. Reliabilism asserts that logic only leads to knowledge if, in the justification of a truth claim, reliable cognitive processes are used. The theory of coherentisim claims that knowledge is secure when it is coherent with other forms of logical constructs. For example' the theory of plate tectonics when originally proposed by Alfred Wagner in 1912 did not cohere with other assumptions held by others in the field and was rejected. However, over the following 40 years more evidence emerged and the evidence began to cohere with Wagner's original theory, which eventually became accepted. Lastly, empiricisim requires that knowledge consists of reason applied to evidence based on observation (Wenning, 2009).

Epistemology is not only concerned with the assumptions about what justifies knowledge, but also with knowledge-generative processes. These processes are: *induction*, *deduction* and *abduction*. Induction is the process of making generalisations from a set of specific cases; i.e., generating theories and laws from observations. Deduction is the generation of specifics based on a general rule identification; i.e. making predictions based on theories and laws. Abduction is the use of analogies to generate further hypotheses from sets of observations and assumptions (Wenning, 2009). In addition, a so-called *hypo-deductive* method can be used, which involves the generation of hypotheses based on observations followed by the testing of these hypotheses. It is that hypotheses can be modified or refuted on the basis of evidence: A hypothesis cannot be proven to be true, rather a theory or hypothesis is provisionally accepted until contradictory evidence emerges (Wenning, 2009). These tenets and processes are the fundamental elements of scientific knowledge generation. In combination, these sources of knowledge and generative practices described above can provide answers to the three fundamental questions with which epistemology is concerned: "What is knowledge, and what do we mean when we say that we know something? What is the source of knowledge, and how do we know if it is reliable? What is the scope of knowledge, and what are its limitations?" (Wenning, 2009, p. 3).

The philosophical underpinnings of epistemology

Epistemological orientation and development is usually described in terms of the philosophical assumptions underlying one's perception of knowledge and knowledge generative processes. In philosophical terms, the varying epistemic positions are described in terms of beliefs about the source of knowledge, about reality and about the certainty of knowledge. The three main themes relevant to science education are *absolutist, realist* and *relativist* positions. Phillips (2008) provides a thorough summary of this dimension of reality and knowledge production, and describes the different epistemological standpoints regarding knowledge as a continuum. At the two ends of the continuum sit "nature the instructor versus humans the creators" (Phillips, 2008, p. 401). 'Nature the instructor', refers to an absolutist and realist epistemology that assumes the existence of an objective reality; knowledge is a result of discovering and making sense of this objective reality. The other end, 'humans the creators' refers to a relativist position that assumes that the perceived world is a construct of the mind and is therefore situated 'in the heads of people' alone. In this view, knowledge varies from person to person and depends on their previous experiences; reality is relative to the knower.

Within relativist epistemology two main ideologies can be distinguished: *individual* or *radical constructivism* and *social constructivism* or *constructionism* (re-named to constructionism to differentiate it from social constructivism in psychology). Radical constructivism starts from the assumption that knowledge is solely located within the knowing subject, is based on individual experience, and is therefore individually created (Phillips, 2000). In contrast, the main tenet of social constructionism is that the creation of knowledge occurs through social interactions within knowledge creating-communities, cultures or groups. It is therefore a product of social interaction rather than being an individual act. One of the most influential authors of social constructivism, T. S. Kuhn, argues that the very existence of science and the content of science depends on the vested interests of powerful groups (political, scientific, business or otherwise) handing down power to a chosen scientific community - the beholders of certain paradigm - for scientific advancement and knowledge production (T. S. Kuhn, 2012). Therefore, the knowledge production process is subject to social, political and economic pressures, is culturally relative and influenced by power relations and partisan interests (Phillips, 2007).

The *aim* of knowledge also, varies according to epistemic orientation: While absolutists aim to discover and describe a universal *truth*, realists seek to find universal *theories* that best accommodate the valid and reliable evidence, and relativists pursue truth that is accept within personal or social frameworks, and consistent with reliable and valid evidence (Hofer & Pintrich, 1997).

One of the most significant points of disagreement regarding philosophical orientations to science epistemology is whether the development of a realist (perhaps post-positivist) or a constructivist orientation should be supported in science education. Constructivist orientation is advocated by, for example, Collins and Pinch (1993); Latour and Woolgar (2013); Von Glasersfeld (1995) and Lederman (2007). According to this position knowing is an adaptive process, knowledge is constructed in the minds of thinking people, individually or through social exchanges, and is determined by the social settings of individuals. Therefore, knowledge is only viewed as a subjective representation of a reality that is relative to the knower (Deng et al., 2011). Such views are summarised by Latour and Woolgar (2013):

> "Science is a form of fiction or discourse like any other, one effect of which is the 'truth effect,' which (like all literary effects) arises from textual characteristics, such as the tense of verbs, the structure of enunciation, modalities and so on." (p. 184)

On the other hand, constructivist theorists holding social realist positions, criticise such views sharply. For example Matthews, for example, in his introduction to *The Nature of Science in Science Education Rationales and Strategies* (McComas, 1998) warns that the recognition of personally or socially constructed *nature of science* knowledge "does not mean that 'anything goes' or 'all ideas and world views are equal' or 'science is just a social construction'." (p. xvi). Longbottom and Butler (1999) voice similar concerns when they assert that "if we go along with those who deny that modern science provides a privileged view of the world… we fall into an abyss where sceptical postmodernists, who have lost faith in reason, dismiss all knowledge claims as equally arbitrary and assume the universe to be unreliable in its behaviour and incapable of being understood" (p. 482). In other words, abandoning belief in the traditional objective foundations of scientific method would lead to a position in which no rational basis was left for knowledge claims (Hodson, 2014). In the educational realm, this area of contestation is reflected in the lack of agreement on what exactly should be included in the tenets of *nature of science* and which philosophical position should be viewed as advanced epistemological orientation.

CHAPTER 3

The origins of epistemological development in education: A historical overview

A brief historical overview of the education provides an insight to the ideologies and motivations that underlie current educational discourses in present times by showing why and how epistemic development was included in the earlier curricula. The inclusion of epistemic development in educational programs since the Greek liberal education programmes has been associated with the cultivation of intellect to develop skills of reasoning. The development of such skill then leads to intellectual authority that allows people to rely on their own judgement regarding knowledge claims, rather than being dependent on some form of authority – religious, political or other forms of authority.

Liberal education

The original conceptualisation of science epistemology in education was founded on a mainly liberal education tradition. In ancient Greece liberal and utilitarian education tradition were segregated on the basis of social class. Liberal education was intended for students who would not depend on manual labour for a living, and aimed to develop habits, emotions and intellect for the cultivation of leisure, whereas for the labouring class, education was intended to reinforce the efficiency and enjoyment of labour (Dewey, 2007). Essentially then, the aim of liberal education is the cultivation of the minds of those who are free to do things for their own sakes and also to develop of thought to equip ruling citizens to make judgements on complex issues (Bailey & Barrow, 2010). Liberal education ideals became important in the Ancient Greek and Roman cultures, partially informed education in the late medieval period, and have become especially prominent since the Enlightenment. These have been applied more universally in some settings although the liberal – utilitarian divide remains.

The assumption that scientific investigations and reasoning are pivotal to the development of the intellect reflected 19th century arguments promoting science education and the development of science epistemology. This is evident, for example, in the works of one of the most prominent science educators of the time, T. H. Huxley, who argued that the power of science engenders the advancement of intellect by supporting the development of observational and inductive abilities (DeBoer, 1991):

> "The great peculiarity of scientific training, that in virtue of which it cannot be replaced by any other discipline whatsoever, is this bringing of the mind directly into contact with fact, and practicing the intellect in the completest form of induction; that is to say, in drawing conclusions from particular facts made known by immediate observation of Nature" (Huxley, 1904, p. 126).

The development of the capacity for independent thought was not only seen to be important for intellectual advancement but also for a transfer of authority from a religious basis to a rational basis (Turner, 1978). Essentially, the motivating force behind this shift in social and intellectual authority was an epistemological shift in the perception of knowledge and truth, from *belief* to *justified belief*. *Belief* might be handed down from an authority figure, for example the church, whereas *justified belief* is based on first-hand experience (observation) and on reasoning. Mid-19th century scientists, such as Huxley, Tyndall and Henry Mausden demanded that the authority of critical reason and empirical verification replace the authority of religion:

> "The improver of natural knowledge absolutely refuses to acknowledge authority, as such. For him, scepticism is the highest of duties; blind faith the one unpardonable sin. And it cannot be otherwise, for every great advance in natural knowledge has involved the absolute rejection of authority, the cherishing of the keenest scepticism, the annihilation of the spirit of blind faith; and the most ardent votary of science holds his firmest convictions, not because the men he most venerates hold them; not because their verity is testified by portents and wonders; but because his experience teaches him that whenever he chooses to bring these convictions into contact with their primary source, Nature — whenever he thinks fit to test them by appealing to experiment and to observation — Nature will confirm them. The man of science has learned to believe in justification, not by faith, but by verification." (Bibby & Huxley, 1871, p. 72)

The assumption that the development of inductive reasoning skills can enable students to independently draw conclusions from evidence, thus freeing them from a dependence on the intellectual authority of others, informs both *scientific literacy* and *powerful knowledge* discourses in modern education policy.

The liberal education tradition is typically characterised by the view that education is a vehicle for the introduction of the traditions and culture of academic disciplines, such as their methodologies, assumptions, limitations and histories (American Association for the Advancement of Science, 1891). Since the late 19th century science has been a cornerstone of liberal education, following the rapid scientific advancements of the Enlightenment. The modernisation argument - the claim that the changing world required independent judgement rather than a passive acceptance of authority – has not only influenced a shift from classical education towards an increasing prominence of mathematics and science, but also promoted the development of rational thought.

Two main lines of interrelated arguments promoting a more comprehensive study of epistemology influence educational discourse and both arguments are related to liberal education ideals. One, reflected in the *powerful knowledge* discourse, focuses on intellectual development, and therefore empowerment through intellect. The other, relating to *scientific literacy* discourse, argues for more emphasis on science education with attention to epistemic development in order to serve political ends; in particular, education for citizenship.

The liberal vs. utilitarian divide

The technological advancements of the Industrial Revolution and the subsequent exponential growth of the public education sector led to a renewed emphasis on the divide between liberal and utilitarian educational aims. While high school enrolments to public schools increased in the United States by 300 percent – between 1886 and 1900 (Rudolph, 2005), only a small proportion of students continued their studies at college level. This, and a requirement for higher technological knowledge in the working class, contributed to bringing utility arguments to the fore, distinguishing between the elitist aims of intellectual authority and the utilitarian role of science in industry, agriculture and manufacturing.

The developments in science education and the formulation of educational discourses are often highlighted in the contexts of British and American education; because the interplay between the Industrial Revolution and public schooling is well documented and, as early industrialist countries, they led these reforms. The endorsement of science epistemology in

British education was based primarily on liberal educational ideals and was expressed mainly in terms of individual personal development. The whole concept of studying science for intellectual development coincided with the 19th century educational reforms for the 'upper classes', so initially, science epistemology teaching was intended for the education of the elite (DeBoer, 1991). The instruction followed from liberal ideas of the development of intellectual capacities for independent thought with a stress on epistemic developments and rigorous inquiry.

Stephens and Roderick (1983) provide a detailed account of the emerging arguments for the inclusion of science education in public education syllabi during industrial revolution. One of the aspects, according to their research, was the provision of practical scientific instruction to ensure that workers would be equipped to work in a more technologically advanced environment. This in turn became a key element of the emerging assumption that education was essential to economic growth, thus precipitating a shift from the traditional liberal view of intellectual development for personal autonomy, to a utilitarian view, promoting education for the development of employment-related skills. At the time of the Industrial Revolution education reformers turned to science education to contribute to the growth of the industrialisation process. From this point onward, science education was deemed to be pivotal for economic growth (Stephens & Roderick, 1983). This applied educational objective gained prominence during the 20th century and was greatly accelerated by the growth of military industries following World War Two (Rudolph, 2005).

Both liberal and utilitarian discourses are sustained in current educational policy. Utilitarianism underpins the contemporary policy of *education-for-economic-growth* discourse. It is evident, for example, in the global promotion of science, technology, engineering and mathematics (STEM) subjects for economic growth (Gluckman, 2011; Lewin, 2000). This contrasts with a modern liberal educational discourse, the *powerful knowledge* discourse. This refers to "…[the concepts of] what knowledge can do or what intellectual power gives to those who have access to it. Powerful knowledge provides more reliable explanations and new ways of thinking about the world and acquiring it and can provide learners with a language for engaging in political, moral and other kinds of debates" (Young, 2008, p. 14).

Early 20th century: democratic education

In terms of the historical development of educational orientation to science epistemology, John Dewey's work is noteworthy. Without attempting a full review of his contribution to educational theory, it is important to note that his influence in science education still saturates education policy, curriculum development and practice. The two most important aspects of his educational theory, in terms of science epistemology in education, are on one hand the advancement of liberal educational ideals and on the other, the constructivist educational approach.

Dewey's educational theory was influenced by progressive education assertions of late-19th-century American reform initiatives. At the heart of progressive education theory was the intention to make schools an effective agency of democratic society, where students learn to become actively-participating citizens. Dewey also argued for the development of a truly democratic society through education, in providing both utilitarian and cultural aspects to all social strata. According to his argument, by moving away from a purely utilitarian education of the working class towards a greater balance with intellectual development, liberal education would help to unify society (Dewey, 2007). This aspect of Dewey's educational theory appears to be resurfacing in *scientific literacy* discourse, in terms of democratic participation in socio-scientific issues, and in *knowledge society* discourse in relation to equal distribution of powerful knowledge.

Dewey's other significant contribution to science education is encapsulated in his theory of the implementation and effects of science inquiry in education. Dewey argued for pedagogy to focus on sciences as a method of thinking rather than as an accumulation of facts. Dewey's most noteworthy assumption informing science education and the development of science epistemologies is, however, the separation of practical (laboratory) work and scientific method as a *mental method*. Practical work gained prominence during the educational reforms of the 19th century; however these were a collection of quantitative laboratory methods rather than actual scientific inquiries. By the end of the century, this laboratory work dominated the high school curriculum and, with the rise of utilitarian and progressive movements, the effectiveness of these was questioned. Dewey steered away from Edward Thorndike and Stephen Forbes' focus on the pure scientific reasoning - characterised by the formal elements of inductive and deductive logic. Instead he developed an instructional model based on the *scientific method* (Rudolph, 2005). Dewey was more in favour of a curriculum that is personally meaningful to students and focused on helping them to understand the scientific approach and its use in everyday life. This ultimately meant a focus on the process of knowledge construction rather than on the content of the knowledge itself. Through the development of his five-step scientific method Dewey combined some aspects of inductive logic, deductive logic and practical work, formulating a now widely-used instructional approach (Rudolph, 2005). Dewey's work is significant in the development of science epistemology because it emphasises that students should develop an understanding of how reliable knowledge is generated, and what kind of evidence is required to validate given types of belief. According to his views, the power of science resides in the ability to make knowledge by transforming guesswork and opinion into justified belief, using relevant evidence (Rudolph, 2005).

Over 100 years of philosophical development since the industrial revolution has seen a marked increase in the focus on science education. This is a result of resulted from a view science as a pivotal factor in the development of the intellect for liberal education of the elite, as a vehicle for economic and social progression and an emancipatory contributor to the achievement of fully democratic society. These arguments are still apparent in *scientific literacy*, *powerful knowledge*, *science education's role in economic development* and *knowledge society* discourses, thus informing policy, theory and practice today. They not only laid the foundations of current policy discourses but also shaped our perceptions about what constitutes science epistemology and why it should be included in science curricula.

CHAPTER 4

Discourses supportive of the development of science epistemology in current education policy

In this section, two educational discourses are introduced, *powerful knowledge* and *scientific literacy*. Both promote the development of science epistemology and inform research and education policy. The *powerful knowledge* discourse advocates the acquisition of disciplinary knowledge in general, which involves the uses of discipline-specific language, types of reasoning and the power and limitations of the knowledge produced in the parent discipline, viewed as a means for promoting social mobility. The *scientific literacy* discourse specifically relates to science epistemology in terms of the development of skills and attitudes of future citizens, so that they will be able to engage effectively in socio-scientific issues.

Powerful knowledge

The powerful knowledge discourse in education serves as a narrative in research and policy for the wider implications of epistemic development. The questions, 'whose knowledge counts?' and 'what counts as knowledge?' are especially dominant in critical social-realist circles because they maintain that "… knowledge is socially constructed … and school knowledge has the symbolic power to maintain social domination … [BUT] accurate knowledge of the world can be obtained and should constitute a non-arbitrary element of the school curriculum" (Nash 2004:605-6 cited in Gerwitz & Cribb, 2009). At the heart of the argument is a focus on the role of education in social power struggles and analyses of how power is reproduced and contested in society through education. Education from this point of view is a manifestation of power and an integral contributing mechanism through which power is maintained (Apple, 2004). Essentially there is a seemingly- unresolvable conflict in the perception of compulsory education: On the one hand, it could be viewed as if the aim of the "powerful class' was to design an educational system that reproduces the social stratification by policies and pedagogies for the production of cheap, compliant, but cultured labour. On the other hand, compulsory education also can be viewed as vehicle of social mobility (Kellner, 2009).

At the core of the powerful knowledge discourse lies the distinction between knowledge that can be attained through experience, and knowledge that is beyond experience, abstract, universal and exists independently from the knower. Different researchers refer to these two distinct types of knowledge in various ways. For example Durkheim distinguishes between experiences or profane knowledge and concepts or sacred knowledge (Schaub, 1920), Berstein differentiates mundane and esoteric knowledge (Moor & Young, 2001; Wheelahan, 2007), Young discerns everyday knowledge and school knowledge (Moor & Young, 2001; M Young, 2009) and Wheelahan (2007) refers to the higher-order knowledge as disciplinary or powerful knowledge (Wheelahan, 2007). According to the *powerful knowledge* argument the vehicle of the reproduction of social classes is an unequal distribution of disciplinary knowledge; therefore, to overcome the segregation of classes, students would need to acquire powerful or disciplinary knowledge. This implies occupying different disciplinary perspectives, using disciplinary language, and the methods and reasoning of the parent disciplines. Disciplinary knowledge requires the development of a critical epistemic stance and the understanding of power and limitations of knowledge in a given field of study. Sociologists promoting the acquisition of disciplinary knowledge are often critical of learner-centred methodologies, such as inquiry learning and competency based curricula. According to their argument, discipline-specific knowledge cannot arise from everyday experiences, based on students' student-led learning Wheelahan, 2007; Young, 2008; Young 2010a, 2010b)

The powerful knowledge discourse therefore promotes the development of epistemic aspects of the various learning areas – including science – to enable students to go beyond everyday experience and simple content knowledge to arrive to an understanding of subject specific reasoning. This is because curricular knowledge is not neutral; instead it works in favour of particular social interests by being embodied in the knowledge form itself (Apple, 1979). Apple theorises the existence of 'knowledge of the powerful', which is distributed unevenly in education and therefore "redistributes social class and status by distributing educational (abstract) knowledge that leads to power and status" (Sheehan, 2011, p. 19). Therefore through an equal access to 'powerful knowledge' has an emancipatory effect.

Scientific literacy

Science literacy is a very broad term that comprises all educational goals aiming to address various aspects of scientific enterprise and it is primarily concerned with the formulation of skills and attitudes at school, enabling future citizens to engage with science-scientific issues intelligibly. Socio-scientific issues are complex, ill-structured problems that are often controversial because they encompass different viewpoints connected to science content, with a social significance. For this, students are required to consolidate scientific knowledge with the economic, ethical, moral, political and social aspects of a problem (Eastwood et al., 2012). Tytler, Duggan, and Gott (2001) define a scientifically literate person as one "who can achieve a functional understanding of, and response to, science-related phenomena that impact upon the individual's life, including issues canvassed in the media" (p. 345).

Originally, this term seems to have been introduced in to the U.S. literature by (Hurd, 1958) and, while it was received with enthusiasm, it did not have an agreed meaning until 1966. At this time Pella, O'Hearn, and Gale (1966) suggested the inclusion of the following aspects of scientific enterprise: basic concepts of science, ethics of science, and the interrelationships between science and society and science and technology. The renewed interest and focus on science education occurred during the so-called Sputnik Era in the American education, which signified a turn from progressive education to a greater emphasis on academic achievement. At the time – and from then on - science, mathematics and technology were portrayed as means for economic advancement for the nation; therefore these learning areas were especially targeted in education (Matthews, 1995). This point is captured in a statement made by The Royal Society (1985): ”[*scientific literacy*] can be a major element in promoting national prosperity, raising the quality of public and private decision making and enriching the life of the individual” (p. 9). A similar argument is still present in current education policy and is evident for example in the promotion of STEM subjects for economic growth (Gluckman, 2011; Lewin, 2000).

It is beyond the scope of the present paper to give a full account of the progression of the *scientific literacy* construct over the past five decades. In terms of science epistemology the *procedures of science* aspect is most noteworthy. According to Shamos (1995), this feature is concerned with knowledge in terms of the development of theories, the role of questioning, analytical and deductive reasoning and reliance on objective evidence. Bybee et al. (1990) refer to it as *conceptual* and *procedural science* and also distinguish *multidisciplinary scientific literacy* relating to the *nature of science*. Tytler et al. (2001) reviews the literature in terms of which aspects of science understanding should be emphasised in order to enable meaningful public engagement in science-related issues. They put forward a conceptualisation of *scientific literacy* that is concerned with various aspects of the scientific process, especially science inquiry and the concept of scientific evidence.

In this context *scientific literacy* presumes a shift in science education from viewing science as a body of knowledge to an understanding of internal processes of science by which knowledge is generated and validated (Tytler et al., 2001). The former is often referred to as science-as-content and the latter, as science-as-process (Moor & Young, 2001). Elsewhere the distinction has been referred to as scientific knowledge versus knowledge-about-science (Driver, Leach, & Millar, 1996). Knowledge about science not only refers to science epistemology but also includes an appreciation of the purpose of science; a search for explanations of natural phenomena; and the ways in which science knowledge interacts with wider culture and society. This interaction includes both the effect of science on different aspects of society and the socially-embedded nature of scientific knowledge construction. This aspect of *scientific literacy* involves both aspects of the present research: scientific inquiry and the concept of evidence are tackled by the *scientific argumentation* sections and the concept of socially-embeddedness by the *nature of science* sections.

CHAPTER 5

The development of epistemology in education

Three lines of educational research address aspects of epistemological development: *personal epistemology, nature of science* and *scientific argumentation*. The first, *personal epistemology*, initially emerged from psychology and it is mainly concerned with the ways in which epistemic orientations influence learning and instruction. While the present research does not aim to address the implications of the development of science epistemology on learning and instruction specifically, this area of research is nonetheless relevant, for three reasons. First, research on *personal epistemology* provides a definition of knowledge, as well as a theoretical framework for understanding the ways in which knowledge is created, its location and the relationship between knowledge and education contexts. Second, it provides several analytical frameworks to distinguish between epistemological orientations. Third, findings from this body of research are often referenced in studies about science epistemology, and especially in studies about *nature of science.*

The concept of *nature of science* arose at approximately the same time that *scientific literacy* aims appeared in science education policy documents. The *nature of science* construct comprises aspects of various social aspects of science including its history, sociology, and philosophy. Furthermore, it is informed by research from psychology and explores "what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours" (McComas, 1998, p. 4). *Nature of science* is often equated with the concept of science epistemology and is commonly used in curriculum documents worldwide to address aspects of science endeavour.

The *scientific argumentation* concept refers to the process of making theoretical claims based on evidence. This requires an understanding of criteria for the evaluation of evidence and the ways in which evidence is used in the construction of explanations. These conceptions are fundamental elements of science-knowledge building and therefore inseparable from science epistemology. Without an understanding of scientific argumentation, concepts such as sources of knowledge, reliability of knowledge, scope and limitation of knowledge and even knowledge itself, are not meaningful.

The present inquiry mainly focuses on aspects of the *nature of science* and *scientific argumentation* to explore epistemological development in senior high-school students. However, the inclusion of a *personal epistemology* framework provides a foundation for the philosophical underpinnings of science epistemology, which is especially relevant to *nature of science*.

Personal epistemology

Personal epistemology – individual beliefs about knowledge construction – is the subject of a significant branch of educational research on epistemology. Generally, studies on *personal epistemology* are concerned with the ways in which personal belief and philosophical orientation influence the learning processes, especially its impact on argumentation, critical thinking, problem-solving and achievement. Other research has focused on investigating the effect of epistemological development on other aspects of intellectual development such as conceptual change, self-regulated learning, theory of mind and motivation (Bendixen & Feucht, 2010; Hofer, 2001, 2008; Hofer & Pintrich, 1997; D. Kuhn & Amsel, 1988). These areas of research, in the majority of the cases, involve tertiary students, leaving a substantial gap in the literature, concerning the epistemological development of primary and secondary students.

The construct of *personal epistemology* is a field of study that rose cognitive psychology. Its theoretical basis is referred to as constructivism. In an attempt to differentiate it from other meanings of constructivism, it is referred to as cognitive constructivism by Grandy (2007) and Brooks (2002), personal constructivism by, for example, Bachtold (2013), (Cobern, 1993) and (Baviskar, Hartle, & & Whitney, 2009). Cognitive constructivism is concerned with the process of individual learners' knowledge construction.

The two most influential cognitive-constructive theorists were Piaget and Vygotsky, whose work dominated educational research in the middle of the 20^{th} century. The main tenet of the theory of cognitive constructivism is that knowledge is created individually by learners' cognitive structures as a result of the reconstruction of mental schema through experiences with phenomena (Haury, 1993; Osborne & Freyberg, 1985). However, Piaget's and

Vygotsky's theories are distinguished by Piaget's focus on cognitive development through the interaction with phenomena in the world, whereas Vygotsky asserts the importance of social interactions in cognitive development. This is why Piaget's theory is referred to as personal constructivism, and Vygotsky's, as social constructivism.

Epistemologically, Piaget's theory of knowledge and knowledge creation is closest to realist and empiricist epistemologies because the development of knowledge arises from experience – empiricism – and seeks to develop understanding of an objective reality – realism. However, later in life Piaget identified that constructed knowledge never can be an accurate representation of objective reality, but rather, mental structures go through successive changes - referred to as assimilation and accommodation -while actions are performed with the objects of reality. Consequently, knowledge is situated within the learner (Piaget, 1980) and therefore is said to precede relativism.

In contrast, Vygotsky's social development theory – also referred to as the sociocultural approach to cognitive development (Scott, 1998) or social constructivism (Bächtold, 2013) – asserts that higher psychological structures, such as complex concepts and theories and higher mental functioning of the individual arise from social interactions. Vygotsky explains the learning process as occurring at two levels, firstly at an interpsychological (between people) followed by an intrapsychological (inside the learner) level. His theory brings the attention to the importance of interactions of the interpsychological plane and in particular the discursive nature of knowledge development (Vygotsky, 1978; Scott, 1998). Vygotsky distinguishes between spontaneous concepts that can be acquired through direct experience, which endorses Piaget's thesis; however, he claims that complex concepts that are situated at a symbolic level only can be understood with the assistance derived from social interactions.

Epistemologically Vygotsky's social constructivism relates to knowledge in a similar way to Piaget's genetic epistemology, but it makes contributions to the later developed theory of social constructionism by distinguishing between spontaneous and symbolic concepts, especially by recognising the socially constructed and therefore culturally bound nature of symbolic concepts. The transition between realist and relativist epistemology is evident for example in Brunner's (1985) statement referring to Vygotsky's work: "Vygotsky's project [is] to find the manner in which aspirant members of a culture learn from their tutors, the vicars of their culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organised, rule-bound belief systems about what exists, about how to get to goals about what is to be valued" (Bruner, 1985, p. 32).

People with different epistemological orientations have different deeply held beliefs about the origins and acquisition of knowledge. Hofer's (2001) comprehensive review of the literature on epistemic development and its implications identified a lack of agreement on the terminology used in related research and listed the following associated terminology: epistemological beliefs, reflective judgement, ways of knowing, epistemological reflection, epistemological theories, and epistemic beliefs. (See Hofer (2001) for an in-depth explanations of these terms.)

While there is a fragmented terminology in the related literature, Hofer and Pintrich (1997) identified some common themes amongst the various conceptualisations of knowledge. These encompass two main dimensions: nature of knowledge and nature of knowing. Each of these is divided to further two-two dimensions. The nature of knowledge is separated into certainty of knowledge and simplicity of knowledge and nature of knowing into source of knowledge and justification for knowing. This conceptualisation of the dimensionality of knowledge is illustrated by Figure 5.1.

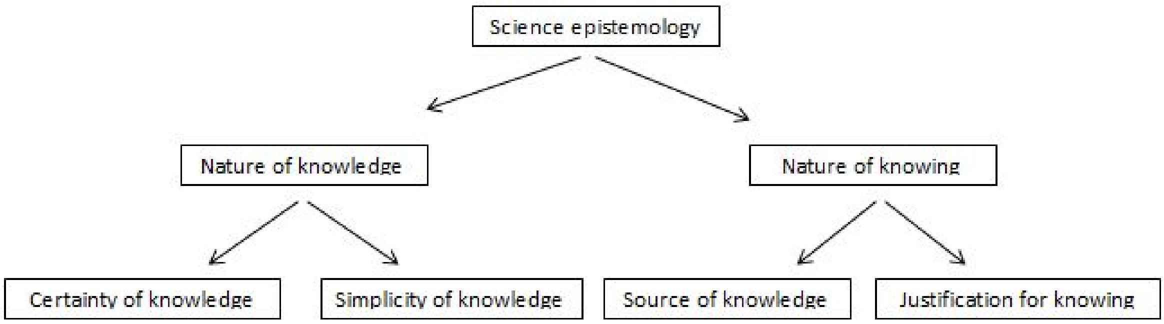


Figure 5.1: The dimensionalities of knowledge

The meaning of these dimensionalities is best demonstrated by showing in the development through various stages of progression. For this the *argumentative reasoning* model of epistemic development will be used, as this the most commonly used model in the field of science education. The model was developed by Kuhn and explained in more detail in Hofer's (2001) review alongside with the other four schemes.

Table 5.1: The development of the four dimensionalities of knowledge through the three stages of epistemic positions: absolutist, realist and relativist

		Absolutism	Realism	Relativism
Relationship between reality and knowledge		The aim of knowledge is to discover and describe the objective, external reality. All phenomena pre-exist and are then discovered by the knower.	Mind and objective reality are separate entities. Changes of mental schema due to sensory experiences theories and explanations are generated to best describe the objective reality.	There is no objective external reality, knowledge and reality is relative to the knower – whether realities are relative to society or person depending on philosophical underpinnings.
Nature of knowledge	**Certainty of knowledge**	Certain, absolute truth, right or wrong	Knowledge is interpreted and negotiated based on empirical evidence at hand. Knowledge is stable as long as no refuting evidence surfaces.	Knowledge is interpreted and negotiated based on empirical evidence at hand. Knowledge is stable as long as no refuting evidence surfaces. Not independent from the culture and society in which it is produced, therefore its validity is culturally/personally embedded. Not concerned about the establishment of absolute truth as truth is relative to the culture/person.
	Simplicity of knowledge	Simple facts	Complex, accumulative, knowledge is evolving based on multiple evidence.	Complex, accumulative, knowledge is evolving based on multiple evidence.
Nature of knowing	**Justification of knowing**	Knowledge requires no justification	Knowledge requires justification and the justification is based on the evaluation of the strength of the evidence.	Knowledge requires justification and the justification is based on the evaluation of the strength of the evidence. Justification exists within the perimeters of social, cultural and historical contexts.
	Source of knowledge	Reliance on authority	Derived from evidence and reason, it is constructed, endures time but fallible. Experts advance it but it needs to be critically evaluated.	Derived from evidence and reason, it is constructed individually or in a social context and ideally is based on critically evaluated evidence, however it is subjective or relative.

Table 5.1 shows the way in which the four dimensionalities of knowledge develop through the three stages of epistemic development: absolutist, realist and relativist. This indicates a shift from seeing knowledge as absolute truth consisting simple facts to a constantly evolving and negotiated understanding of the reality based on multiple justified evidence.

These conceptualisations of the stages of epistemic development or epistemological positions inform much of *nature of science* research as well. The pivotal role of these developmental stages – that also correspond with philosophical positions – is that the members of the various research communities shaping the conceptualisation of the nature of *science tenets* seem to be in disagreement about which of these positions should be considered most advanced. Essentially, some of the nature of science tenets – for example that the collection and interpretation of scientific evidence is influenced by personal subjectivity and existing theories or that scientific knowledge is the product of human imagination and creativity –can be interpreted as a view that knowledge is relative to the knower, thus representing a relativist position. Disagreement regarding whether or not relativist position should be assumed to be the most advanced position obviously leads to a lack of consensus about the *nature of science* construct itself. It is important to note that scholars holding realist views warn that a relativist position in relation to scientific knowledge, - the assumption that all knowledge claims are of equal value - would erode the significance of knowledge based on rational thought and lead to a position that the universe cannot be reliably understood.

Nature of science

The concept of nature of the science is contested. A large body of literature reviews (Deng et al., 2011; Lederman, 1992; Lederman et al., 2002; Lederman, Wade, & Bell, 1998) reveal that the development of the *nature of science* construct began as an understanding of scientific method in the early 1900s and incorporating aspects of psychology, philosophy and sociology of science from the 1980s onwards. Now, the term *nature of science* is used to describe what science knowledge is like, or in other words, it describes fundamental assumptions regarding science knowledge. While it is often interchangeably used with *epistemology of science*, it is apparent that the actual processes involved the advancement of scientific knowledge are deliberately excluded from the *nature of science* tenets. Instead, *nature of science* includes the values and beliefs inherent in the advancement of scientific knowledge (Lederman, 1992; Lederman & Zeidler, 1987; McDonald, 2010). The following aspects are generally cited in the literature (Akerson et al., 2009; Eastwood et al., 2012; Ireland, Watters, Brownlee, & Lupton, 2012; Khishfe, 2012a; Lederman et al., 2002; Matkins & Bell, 2007; McDonald, 2010; Nadelson & Viskupic, 2010; Neumann, Neumann, & Nehm, 2011; Posnanski, 2010; Quigley, Pongsanon, & Akerson, 2010, 2011; Sandoval, 2005; Reneé S. Schwartz, Lederman, & Crawford, 2004) as the main tenets of *nature of science*:

- scientific knowledge is tentative,
- it is created through social interactions and reliant upon empirical evidence,
- is partly the product of inference,
- it is socially and culturally embedded,
- theory laden,
- scientists' creativity and imagination is crucial and
- theories are different from laws

The distinction drawn in the literature, between *science inquiry* and *nature of science* is that *science inquiry* refers to the activities that form the process of science inquiry, whereas nature of science is concerned with the epistemological assumptions underlying those activities (Lederman et al., 2002). While researchers emphasise a distinction between *science inquiry* and the *nature of science* research regarding the development of *nature of science* conceptions reveal that the two are actually intricately bound. For example research *investigating* instruction strategies has indicated that the only the most effective strategy for *nature of science* pedagogy embedded in either authentic science inquiry (Abd-El-Khalick, Bell, & Lederman, 1998; Eastwood et al., 2012; Khishfe, 2012b; Reneé S Schwartz & Crawford, 2004) or linked to scientific argumentation (Khishfe, 2012a, 2012b; McDonald, 2010). The reason for the pivotal role of inquiry or argumentation in the development of *nature of science* conceptions is illustrated, for example, by the tenet that scientific knowledge is empirically derived. This means that scientific knowledge is based on observations - one of the activities of the process of scientific inquiry. However, because observations are constrained by perceptual apparatus, they are therefore to some extent subjective. Consequently, the deliberate separation of science inquiry and nature of science seems to be forced and counterproductive.

The contested ambit of *nature of science* tenets is further evident in disagreement surrounding what should and should not be included in the list of tenets. The development of the *nature of science* concept has involved scientists, philosophers and science educators, and is reinterpreted by policymakers in forming curricula; it is not surprising, therefore, that the identification of a universally-agreed definition has been difficult to achieve. The different stakeholders' views of scientific knowledge-construction differ according to their perspectives; historians focus on paradigm shifts, philosophers are concerned with validity and knowledge justification, sociologists emphasise social interactions and power relationships and scientists draw on their specific areas of expertise and view varying aspects as significant (Northcott, 2014; Reneé S Schwartz & Lederman, 2008). The result is untidy, so most of the different stakeholders – such as philosophers (Alters, 1997; Feyerabend, 1993; T. S. Kuhn, 2012; Latour, 1987), scientists and educators (Gabel, 1993; Hodson, 1985; Hodson, 1986, 1988; Lederman, 1992, 2007; Matthews, 1994) – only really agree upon the lack consensus regarding the construct of *nature of science*.

Moreover, what appears to be another significant gap in the research towards the formulation of a valid and reliable construct is the lack of involvement of actual philosophers or scientists. This is noted for example by Alters (1997) and Ryan and Aikenhead (1992) who note that, although *nature of science* instruments are claimed to be based on philosophical positions, these instruments are written by science educators not by philosophers. This has been recognised by some other researchers; for example Fensham (2002) argued that the content of the *nature of science* construct has been determined by science educators, while actual scientists have had little influence on the shaping of the tenets and the interpretation of their meaning. This in turn has led to significant discrepancies between what is portrayed as a pivotal aspect of science epistemology by, for example, philosophers and what is actually perceived as being the important aspects of the scientific enterprise.

Much of the formulation and validity of the construct is founded upon lines of research assessing a) students' *nature of science* conceptions and its development, b) teachers' understating of *nature of science*, c) validity and reliability of *nature of science* instruments and d) the presence of nature of science in curriculum documents. From this it becomes evident that most of the research relies on a construct that has not been defined accurately at the first place and its content only has been reinforced by accumulating research using their discordant construct.

In the present study the main focus of the literature review is to identify the extent to which *nature of science* is reflective of philosophical positions of philosophers and how well represents scientists' opinions about scientific enterprise. This is leading to a more accurate conceptualisation of the *nature of science* construct.

Educators' perspectives

The area of contestation among educators is mainly around the extent to which science inquiry should or should not be included in *nature of science* instruction. While it is acceptable to say that in general most constructs are contested and changing over time it appears that there is one particular, critical disagreement amongst researchers of the conceptualisation of *nature of science*. There is a general agreement that *nature of science* and science inquiry are inherently interlinked (F. Abd-El-Khalick et al., 2004; F. Abd-El-Khalick, Boujaoude, S., Duschl, R., Lederman, N., Mamlok-Naaman, R., Hofstein, A., et, 2008; F. Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick et al., 1998; Duschl, Ellenbogen, & Erduran, 1999; Duschl & Grandy, 2008; Duschl & Osborne, 2002; Lederman, 2007). However, the extent to which a distinction is drawn between *nature of science* and inquiry might be critical to students' epistemological development; the philosophical assumptions and social implications of science are meaningless unless its actual processes are understood.

A significant body of literature is in agreement with Lederman's (2006, 2007) assertion that *nature of science* is separate from scientific inquiry, as is evident from the most widely accepted tenets (listed above). Lederman argues that science inquiry - including scientific processes such as collecting and analysing data, and drawing conclusions – is intimately related to *nature of science*, and yet distinct. The distinction is that the former construct essentially comprises the *processes of science*, whereas the latter is an explanation of the *philosophical underpinnings* of those processes. The philosophical underpinnings include concepts such as observations being theory-laden and constrained by perceptual apparatuses and so on. Lederman's description does not address the mental processes associated with the collection and processing of scientific data. These include, for example, the assessment of data quality, making inferences based on statistical analysis, consideration of other factors such as sample size and sample bias, and the ability to distinguish between correlation and causation. Table 5.2 shows a set of learning aims associated with epistemic development. While some – such as *scientific explanation* and *science communications* - are included in the *nature of science* construct, others are not amongst Lederman's (2006, 2007) commonly accepted tenets. These are: *assessing the quality of data*, *study design* and *uncertainty of data*. It is unclear why all of these seemingly pivotal aspects of science epistemology should not be included. These aspects are crucial, because, for a scientist engaged in an investigation it is these mental processes that link empirical processes with philosophical commitments.

Other researchers have also criticised the absence of science inquiry from the conceptualisation of nature of science. For example, Hodson (2014), J Ryder, Jones, and de Vries (2009) and Deng et al. (2011) argue that scientific inquiry and science epistemology are related conceptually, procedurally and pedagogically. Hodson (2014) observes: “ much of our scientific knowledge and, therefore, consideration of its status, validity and reliability is intimately bound up with the design, conduct and reporting of scientific investigations” (p. 911). This appears to be a noteworthy point, given that science epistemology – of which nature of science is claimed to be a part – is about the source, limitation and certainty of knowledge. Lederman (2006), in attempt to address Hodson’s concern, suggests that the cause of confusion could be the phrase ‘*nature of science’*; asserting that ‘*nature of science knowledge’* might be more accurate. This is possibly beside the point: If the definition of nature of science as “epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge” (Lederman, 2006, p. 4) then the actual assumptions underlying it and the processes leading to knowledge are inherently a part of the concept because the assumptions are meaningless in isolation

Table 5.2 Epistemic learning aims to achieve science education for citizenship in compulsory school science (Jim Ryder, 2002, p. 643)

Assessing the quality of data

Students should:

(a) recognize that measurements carry an inherent variability and, therefore, do not provide unequivocal access to a `true' value;

(b) understand that an estimate of variability can be obtained from the spread found in repeated measurements; and

(c) recognize that if meaningful conclusions are to be drawn then communication of a measurement needs to be accompanied by an estimate of variability.

Study design

Students should:

(d) be aware of a range of methodologies used by scientists to collect data, e.g. *in vitro* and *in vivo* studies, blind and double-blind studies involving placebos, observational studies, and experimental studies involving control of variables;

(e) understand that in population studies sample size and sampling bias have an impact on the validity of the findings;

(f) understand that in experimental studies involving control of variables, the choice of variables to be controlled has an impact on the validity of the findings; and

(g) understand the concepts of correlation, causal link and causal mechanism.

Scientific explanations

Students should:

(h) recognise that scientists use analogies to help them develop new explanations, e.g. the heart as a mechanical pump;

(i) recognise that explanations can involve entities not there to be seen in the phenomenon, e.g. particles of matter in a gas, magnetic field lines, light as an electromagnetic wave;

(j) recognise that theoretical models can be used to generate predictions that can be tested by further analysis of phenomena; and

(k) be able to give examples of controversies that have arisen as a result of scientists using different ideas to explain a single phenomenon.

Uncertainty in science

Students should:

(l) appreciate that many scientific questions are not amenable to empirical investigation because of the number and complexity of variables which would need to be

controlled in an experimental study, the long-time horizons involved, and/or restrictions on study design following from ethical considerations; and

(m) understand that since proof is often unattainable, decisions may need to be made on the basis of estimates of risk.

Science communication

Students should:

(n) understand the role of peer review in the publication of new findings;

(o) be aware that the status, track record and funding source of scientists can influence how their interpretations of data are reported;

(p) recognise that commercial organizations, scientists, government bodies and media reports often present measurements following from scientific investigation without any communication of the reliability or validity of these measurements; and

(q) be aware that in describing disagreements between groups of scientists media reports may provide limited consideration of the strength of each group's case.

Perspectives of philosophers of science

Perhaps the most contested area of the *nature of science* construct concerns the philosophical underpinnings of its tenets. This is unsurprising because the processes of science knowledge production – the development of theory based on empirical evidence – have not changed much in the past 200 years, whereas the philosophical conceptualisation of knowledge, its relation to reality and theories of the social aspects of knowledge production have changed significantly. Cleminson (1990) summarises this shift, taking the reader through the milestones of epistemic development, from positivism, through empiricism, realism, logical empiricism to relativism. She contrasts logical empiricism and the 'new' philosophy underlying the different assumptions about the existence of objective external reality. This philosophy refers to constructivism insofar as the observer cannot be divorced from the observed, therefore making objectivity impossible. The result is two assumptions about science knowledge: that it is theory-laden and socially situated. The developments of understanding regarding these assumptions are represented in the *nature of science* tenets. For example, according to Lederman (2006), scientific knowledge is partially subjective and science as a human enterprise is practised in the context of a larger culture and therefore affected by the various elements in which it is embedded. On the other hand, for example, Giddings (1982), for example, clearly belongs to the realist, camp according to his interpretation of the same tenet: "There exists an objective, external world, independed of the existence of the observer" (p. 21).

Alters (1997) attempted to attain a clearer picture about the relationship between philosophers' positions and different tenets of *nature of science*. The research involved 210 philosophers who completed a 20 item survey. He concluded that there is no commonly agreed-upon philosophical position that underpins the existing *nature of science* tenets. Alters asserted that different philosophers of science hold different views about the tenets and therefore, that the current, commonly accepted philosophical positions of *nature of science* should be reviewed.

While Alters' research is noteworthy in terms of the aim of his inquiry, the study also received criticism for its method. Eflin, Glennan, and Reisch (1999) notes, that contrary to Alters' (1997) findings there are areas of consensus among science educators with regards to the main tenets of *nature of science*. Eflin et al. (1999) identified the following areas of consensus:

- The main point of science is to acquire knowledge of the physical world
- Science seeks to describe the underlying order in the world in a maximally simple and comprehensive manner
- Science is dynamic, changing and tentative
- There is no single scientific method

Then again, the defence of an existing consensus amongst educators based on that consensus itself seems to be circular thinking. Alters' aim was to establish the extent to which a consensus exists among *philosophers* of science about the *philosophical* underpinnings of the *nature of science* construct. Consequently, a consensus sought from educators will not suffice as confirmation and has little relevance to the agreement – or the lack thereof – among philosophers.

Furthermore, the listed items of agreement do not imply a common philosophical position; each of them can be interpreted by taking up different epistemic positions. Essentially, the main problem with the *nature of science* tenets is that they are very vaguely formulated and therefore allow interpretations based on different philosophical assumptions. To illustrate the aforementioned socially and culturally embedded nature of scientific knowledge can be very easily interpreted as being representative of a relativist position. Table 5.3 shows the illustrative terms for naïve and informed views of nature of science aspects. From these excerpts becomes evident that the researcher interpreted the culturally embedded nature of scientific knowledge as how well the knowledge claims are accepted by the society, rather than science theories being subjective explanations of a natural phenomenon, thus relative to the knower. Alters' (1997) statement, "there is no one agreed-on philosophical position underpinning the existing NOS in science education" (p. 48) is supported by Osborne et al. (2003), who advocate for the adoption of a pluralistic approach to teaching about the *nature of science*.

Table 5.3 Illustrative examples of responses to VNOS items (Lederman et al., 2002, p. 516)

NOS Aspect	More Naive Views	More Informed Views
Inference and theoretical entities	Scientists can see atoms with high-powered microscopes. They are very certain of the structure of atoms. You have to see something to be sure of it. (Form B: Item 2)	Evidence is indirect and relates to things that we don't see directly. You can't answer . . . whether scientists know what the atom looks like, because it is more of a construct. (Form B: Item 2)
	There is . . . scientific certainty [about the concept of species]. While in the early days it was probably a matter of trial-and-error . . . nowadays genetic testing makes it possible to define a species precisely. (Form C: Item 7)	Species is . . . a human creation. It is a convenient framework for categorizing things. . . . It is a good system but I think the more they learn the more they realize that . . . we cannot draw the line between species or subspecies. (Interview follow-up on Form C: Item 7)
Theory-laden NOS	[Scientists reach different conclusions] because the scientists were not around when the dinosaurs became extinct, so no one witnessed what happened. . . . I think the only way to give a satisfactory answer to the extinction of the dinosaurs is to go back in time to witness what happened. (Form C: Item 8)	Both conclusions are possible because there may be different interpretations of the same data. Different scientists may come up with different explanations based on their own education and background or what they feel are inconsistencies in others ideas. (Form C: Item 8)
	Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work. (Form B: Item 4)	Scientists are human. They learn and think differently, just like all people do. They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge. (Form B: Item 7)
Social and cultural embeddedness of science	Science is about the facts and could not be influenced by cultures and society. Atoms are atoms here in the U.S. and are still atoms in Russia. (Form C: Item 9)	Of course culture influence the ideas in science. It was more than a 100 years after Copernicus that his ideas were considered because religious beliefs of the church sort of favored the geocentric model. (Form C: Item 9)
	Well, the society can sometimes not fund some scientific research. So, in that sense it influences science. But scientific knowledge is universal and does not change from one place to another. (Interview follow-up on Form C: Item 9)	All factors in society and the culture influence the acceptance of scientific ideas. . . . Like the theory of evolution was not accepted in France and totally endorsed in Germany for basically national, social, and also cultural elements. (Form C: Item 9)

Scientists' views

Various research (Glasson & Bentley, 2000; Osborne et al., 2003; Osborne et al., 2001; Reneé S Schwartz & Lederman, 2008; Wong & Hodson, 2009, 2010) has been conducted to elicit information about scientists' views of *nature of science*. The most noteworthy commonality to emerge is that scientists' views are often not congruent with those commonly referred to as an 'informed' epistemic view in science education literature. Based on this body of research it can be concluded that scientists, in general, hold realist, empiricist or instrumentalist views and reject relativism. There is also a strong consensus about the theory-driven nature of scientific inquiry and absolute objectivism is almost always renounced. Then again, the notion of subjectivity is not equated with the rejection of an external objective reality, nor do scientists tend to accept that scientific knowledge is subjective, personally or socially situated. Rather, scientists set out to provide the best approximation to explanation of the objectively-existing reality, based on empirical evidence, while drawing on competing theories. For most scientists, scientific knowledge is robust and durable insofar as accumulating evidence does not refute it.

Reneé S Schwartz and Crawford (2004) and Glasson and Bentley (2000) discuss some differences between typical views of scientists and educators or philosophers and the typical views of scientists with an understanding of the science process. On the basis of how a scientific investigation is viewed *science process* and the *social practice of science* can be distinguished. The former relates to what scientists actually do during the inquiry process and the latter comprises all the social, political, economic and other interactions surrounding the *science process*. This idea appears to be coherent with *Science Teaching Objectives* listed in Table 5.2 *Assessing the quality of data*, *Study design*, *Scientific explanations* and *Uncertainty in science* are associated with *science process*. *Science communication* is associated with the *social practice of science* which is seen as a disciplinary and goal-directed activity (Rouse, 1996).

The multiplicity of positions held by scientists, according to whether they view the scientific enterprise from a *science-process* or *social-practice-of-science* perspective appears to be confirmed by Glasson and Bentley (2000). In their study they compared scientists' explanations of their research for a teacher audience with their explanations during one-on-one interviews. Glasson & Bentley found that scientists tend to express different views about *nature of science* in the two different settings. When they described their research for the teacher audience, all six participating scientists, from different fields, emphasised the connections between their research and social issues, such as the ways in which certain drugs positively affect societies, increasing agricultural production or recycling. On the other hand, during interviews, scientists tended to highlight the research procedure and discuss the centrality of collecting empirical data. In other words, scientists showed a commitment to empiricism and experimental design in terms of their own research. Then again, scientists also recognised that science is "empirical, yet contextualised and connected to political and social issues" (p. 17), which could be interpreted as a relativist view. However, it is most likely to be an indication of an awareness of the interplay between science and society. Glasson and Bentley do not explicitly imply that the scientist hold relativist position discussing the *social-practice-of-science,* however, a constructivist perspective is referred to as a more advanced position compared to empiricist or post-positivist views. The mere fact that scientists are aware that their research practice is influenced by social and political forces cannot be equated to a constructivist or relativist position. Moreover, scientists described their research as an exclusively empirical endeavour searching for ‘objective truth’, which is reflective of a post-positivist orientation, and seeming to be inconsistent with the views represented in discussions about social impacts. Glasson and Bentley’s research highlights the lack of clarity around philosophical positions. This confusion to some extent clarified in the concluding remarks of the research;

> “ …some hallmark principles of science (e.g. replicability, falsifiability, objectivity) have been negotiated through a social process that includes the socio-political and cultural contexts in which the research is conducted. However, acknowledging the role of social consensus in science does not negate the importance of empiricism in scientific research or in classroom science investigations. The overriding view among practicing scientists is that science is essentially experimental and empirical; however, the important role of theory, the multiplicity and complexity of science methods, and the value-ladenness of science require that scientists examine the assumptions underlying their own research and what goes into the decision-making that affects research design, funding, and public acceptance of results” (Glasson & Bentley, 2000, p. 20).

From this it is evident that the assumptions regarding the philosophical perspectives underlying the *nature of science* tenets is still negotiated. Presumably what is represented in schools as assumptions inherent to scientific knowledge should resemble the view of scientists.

Experts from various fields: Delphi study

Another important aspect of the *nature of science* construct is that some research (Reneé S Schwartz & Lederman, 2008; Wong & Hodson, 2009, 2010) has identified strong agreement regarding the tenets of *nature of science*. In this research the *Views of Nature of science Questionnaire* which was designed to obtain information about assumptions underlying the most widely-accepted tenets was used. This constrains the possible answers and necessarily confirms consensus regarding the content of the *nature of science* construct, because participants are required to express their positions in relation to the existing tenets. The Delphi study conducted by Osborne et al. (2003) is a noteworthy exception. This research aimed to establish empirically the extent of agreement within the wider expert community based on 23 data sets collected from experts from various fields, including historians, philosophers, science educators, scientists and sociologists of science.

The study of Osborne et al. (2001) involved three rounds of survey. In the first round three open-ended questions were distributed to collect information about what aspects of the science enterprise should be taught at schools. The questions were:

1. What, if anything, do you think should be taught about the methods of science?

2. What, if anything, do you think should be taught about the nature of scientific knowledge?

3. What, if anything, do you think should be taught about the institutions and social practices of science?

(Osborne et al., 2001, p. 2)

After coding the responses, 30 broad common themes were identified, grouped into three major categories. These categorised themes were sent back to participants for ranking according to importance, which reduced the number of themes to 18. During ranking participants were requested to rate the importance of each theme on a 5 point Likert scale and provide justification for their ranking. To identify the degree of agreement about the importance of the themes, participants were required to rank them according to their importance to the curriculum. For this they had to decide whether the inclusion of each theme was "essential', 'desirable' or 'optional'. The response 'essential' was limited to 10 choices. The results were then sent back to participants for a third and final round, which resulted in the emergence of 9 themes.

By the use of an open-ended questionnaire, the expression of the researchers' own views and ideas were minimised to reduce the possibility of the data being constrained by the instrument. The Delphi method is essentially a qualitative research tool to establish consensus among experts by facilitating the systematic elicitation and analysis of a panel of experts (Osborne et al., 2003). Table 5.4 shows a summary of the findings.

One of the most important outcomes of this research was that it “provided empirical evidence of a consensus on salient features which are both significant and essential components of any basic knowledge and understanding about science and, in addition, uncontroversial within the relevant academic communities within an interest in science education” (Osborne et al., 2003, p. 712). The appearance of sufficient agreement in the data suggests that these themes would be suitable to form the core of the *nature of science* construct.

The other compelling evidence emerging from the study was the very high agreement on many themes of the *Methods of Science* category. While these themes fall into the category of *science inquiry* existing curricula, concepts such as scientific evidence, power, the limitation of scientific explanations and the concept of certainty are often poorly covered in science-investigation topics (R Gott & Duggan, 2007; R Gott & Johnson, 1996; Lubben & Millar, 1996; Roberts & Gott, 2010). Based on the findings Osborne et al. a new curriculum direction is recommended, in which the historical aspects and philosophical assumptions underlying the *nature of science* construct naturally emerge from the process of inquiry and could be achieved by explicit discussions around specific inquiry.

The results of the Delphi study disavow the inculcation of assumptions relating to the significance of socially-embedded and objective or subjective nature of scientific knowledge. None of the consensually agreed-upon themes emerging from the study related to that aspect of the debate. Although undoubtedly these aspects of science knowledge are important for those with an interest in the sociology or philosophy of science, these could not only be irrelevant for the majority of students, but without having understood the *science process* itself, they could well be misleading.

The research literature suggests that there is a firm consensus among scientists about the elements of science curriculum that are required to help students understand how scientific knowledge is advanced, that the development of science epistemology cannot be divorced from the process of science inquiry and that there is no consensus on the ontological underpinnings of science (that is whether there is an objective or subjective reality, and the extent in which knowledge is socially embedded).

Table 5.4 The results of Delphi study showing the consensus among experts regarding the essential elements of science education (Osborne et al., 2001, pp. 55-61)

	Theme title	Theme summary
Methods of Science Themes	Scientific method and critical testing	Pupils should be taught that science uses the experimental method to test ideas, and, in particular, about certain basic techniques such as the use of controls. It should be made clear that the outcome of a single experiment is rarely sufficient to establish a knowledge claim.
	Creativity	Pupils should be taught that science is an activity that involves creativity and imagination as much as many other human activities and that some scientific ideas are enormous intellectual achievements. Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination
	Science and questioning	Pupils should be taught that an important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers, which then lead to new questions. This process leads to the emergence of new scientific theories and techniques which are then tested empirically.
	Diversity of scientific thinking	Pupils should be taught that science uses a range of methods and approaches and that there is no one scientific method or approach.
	Analysis and interpretation of data	Pupils should be taught that the practice of science is reliant on a set of skills required to analyse and interpret data. Ideas in science do not emerge simply from the data but are reliant on a process of measurement and interpretation which often requires sophisticated skills. It is possible, therefore, for scientists to come to different interpretations of the same data
	Hypothesis and prediction	Pupils should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims.
Nature of Scientific Knowledge themes	Historical Development of Scientific Knowledge	Pupils should be taught some of the historical background to the development of scientific knowledge
	Science and Certainty	Pupils should appreciate why much scientific knowledge, particularly which taught in school science, is well established and beyond reasonable doubt, and why other scientific knowledge is more open to legitimate doubt. It should also be explained that current scientific knowledge is the best we have but may be subject to change in the future, given new evidence or new interpretations of old evidence.
Institutions and Social Practices of Science	Cooperation and collaboration in development of scientific knowledge	Pupils should be taught that developments in science are not the result of individual endeavour. They arise from group activity and collaboration, often of a multidisciplinary and international nature.
	Moral and ethical dimensions in development of scientific knowledge	Pupils should appreciate that choices about the application of scientific and technical knowledge are not value free; they may, therefore, conflict with moral and ethical values held by groups within society

Contrary to these findings there is a substantial emphasis on the philosophy, sociology and history of science in curriculum documents internationally. McComas et al. (2002) showed in their qualitative analysis of several curriculum documents that the attributes of *nature of science* are informed by various disciplines, all adding to an understanding of the scientific enterprise. To illustrate this, the authors created a diagram shown in Figure 5.2. The relative sizes of the circles correspond to the approximate extent to which each discipline contributes to the conceptualisation of *nature of science*. It is interesting to note that the absence the *processes of science* from the diagram.

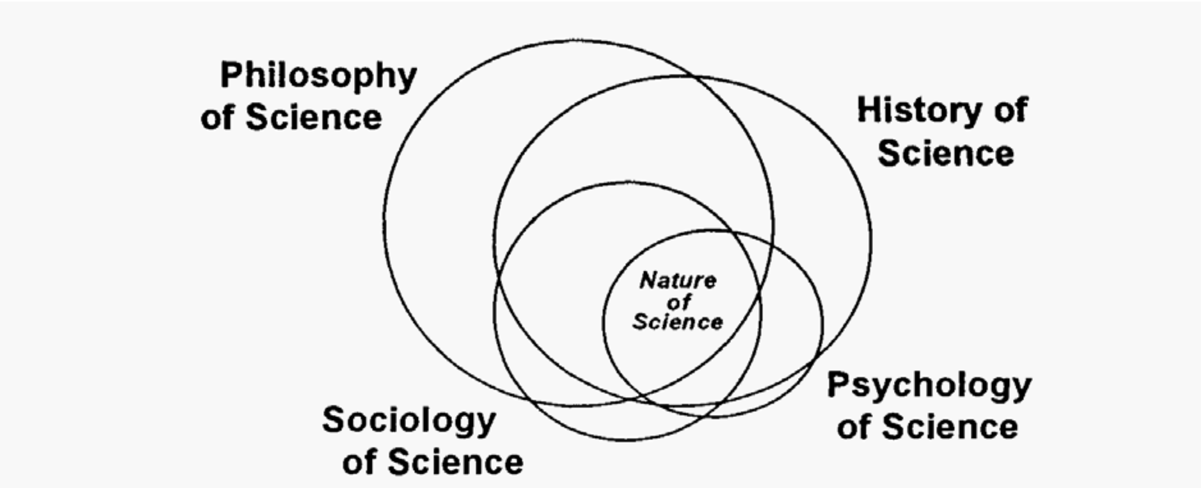


Figure 5.2 Disciplinary fields contributing to the conceptualisation of nature of science based on the qualitative analysis of various curriculum documents. The size of the circles corresponds with the relative influence of each disciplinary field. Note the exclusion of science inquiry (McComas et al., 2002, p. 50)

McComas et al. identified five curriculum documents that include statements that describe what science is and how it is practised; for example that science has inherent limitations, and that science relies on empirical evidence, logical arguments and scepticism. The relative dominance of the philosophy of science in the diagram is contrary to experts views – based on the Delphi study as discussed previously - while the core concepts of science process are not sufficiently represented.

A comparison of expert views on *nature of science* based on the Delphi study and on findings of McComas et al. (2002) shown in Table 5.5 illustrates an overlap between the *nature of science* tenets represented in curriculum statements and what experts would include in the curriculum documents. The difference is that the *nature of science* tenets are generic statements *about* scientific knowledge whereas experts suggest learning the *processes of science* itself, which underlie understandings about scientific knowledge. Essentially, however, the main question remains whether the *nature of science* construct should be considered as a descriptor of science epistemology or rather it should be considered as values and beliefs inherent to science with some sociological aspects of the scientific enterprise.

5.5 Comparison of themes emerging from the Delphi study and McComas and Olson's (1998) study of national standards (Osborne et al., 2003, p. 713)

Comparison of themes emerging from this study with those from McComas and Olson's (1998) study of national standards

McComas & Olson	Delphi Study
Scientific knowledge is tentative	Science and Certainty
Science relies on empirical evidence	Analysis and Interpretation of Data
Scientists require replicability and truthful reporting	Scientific Method and Critical Testing
Science is an attempt to explain phenomena	Hypothesis and Prediction
Scientists are creative	Creativity Science and Questioning
Science is part of social tradition	Cooperation and collaboration in the development of scientific knowledge
Science has played an important role in technology	Science and Technology[b]
Scientific ideas have been affected by their social and historical milieu	Historical Development of Scientific Knowledge
	Diversity of Scientific Thinking
Changes in science occur gradually	
Science has global implications	
New knowledge must be reported clearly and openly[a]	

[a]While this theme did emerge from round 1 of the study, it was not considered important enough by the participants for inclusion in top rated themes in subsequent rounds.
[b]This was not one of the 9 themes achieving consensus but came close with 65% rating its importance 4 or higher.

Argumentation in science

Epistemology focuses on *how* we develop knowledge, and *why* we believe that it is true (Delors et al., 1996). This requires an understanding of criteria used for the selection of evidence, the ways in which evidence is used in explanations, and the construction of explanations. The process of making scientific claims based on evidence is the process of *scientific argumentation* (Roberts & Gott, 2010).

Research on *scientific argumentation* in relation to epistemic development has been primarily concerned with the process of building and evaluating arguments, which has generally involved a critical "coordination of evidence and theory that supports or refutes an exploratory conclusion, model or prediction" (Duschl & Osborne, 2002, p. 44). This occurs in authentic science inquiries, the evaluation of competing theories, and in relation to socio-scientific issues – informing personal and political decision-making. The requirement for coordination of evidence is critical to an understanding of research design procedures, measurement and data-analysis procedures, and the analysis of the reliability and validity of an investigation.

Roberts and Gott (2010) illustrated these processes in the diagram shown in Figure 5.3 by using Toulmin's argumentation pattern (2005). Scientists use the 'looking forward' perspective to construct an argument based on empirical data, supported by Toulmin's concept of warrant and backings, while the rebuttals indicate the circumstances for which the warrant is not merited. The evaluation of other claims takes, in contrast, a 'looking back' perspective and examines the warrants, backings and rebuttals for the data, and assesses how well the claims are supported by evidence.

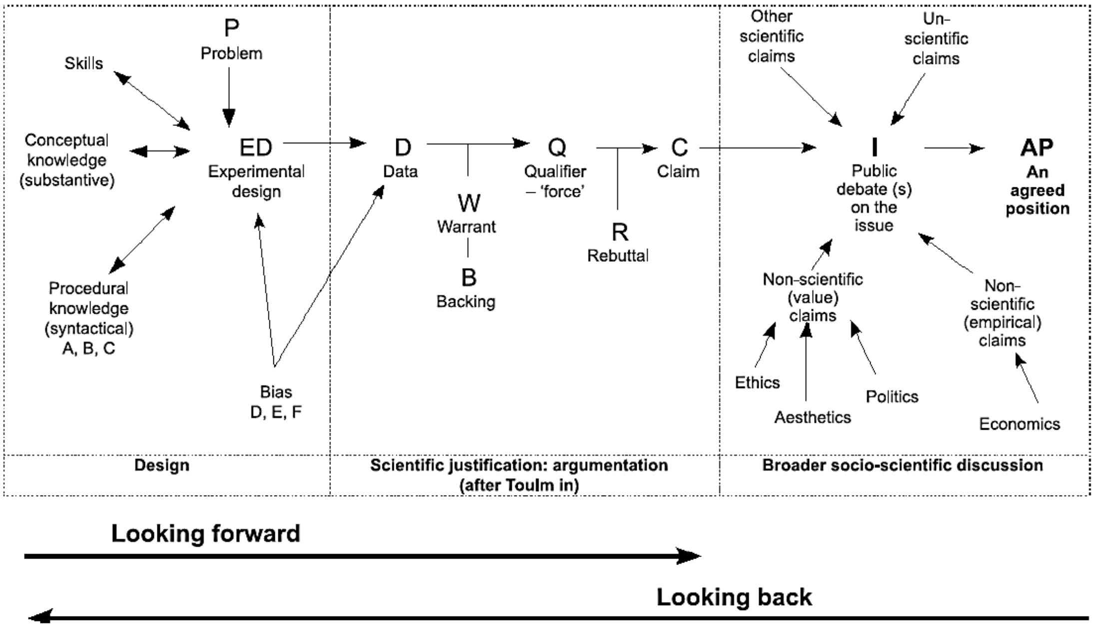


Figure 5.3 Processes involving and influencing the process of scientific argumentation (Roberts & Gott, 2010, p. 207)

Scientific argumentation along both the *looking forward* and *looking back* directions are key driving forces in the scientific knowledge development. Hodson (2014) sums up the role of dispute in science:

> “Real science is impregnated with claims, counter claims, argument and dispute. Arguments concerning the appropriateness of experimental design, the interpretation of evidence and the validity of knowledge claims are located at the core of scientific practice. Arguments are used to address problems, resolve issues and settle disputes. Moreover, our day-to-day decision-making with regard to socio-scientific issues is based largely on the evaluation of information, arguments, conclusions, views, opinions and reports made available via newspapers, magazines, television, radio and the Internet. Citizens need to know the kinds of knowledge claims that scientists make and how they advance them. They need to understand the standards, norms and conventions of scientific argumentation in order to judge the rival merits of competing arguments and engage meaningfully in debate on SSI [socio-scientific issues]. In particular, they need a robust understanding of the form, structure and language of scientific arguments, the kind of evidence invoked, how it is organized and deployed and the ways in which theory is used and the work of other scientists cited to strengthen a case.” (Hodson, 2014, p. 926)

Links between scientific argumentation and science epistemology

A consideration of the main tenets and processes of science epistemology in relation to argumentation in science reveals that rationalism - the idea that logic is a source of knowledge – underpins investigation, the coordination of variables and the mental processes that guide justification to arrive to a claim based on the data. Reliabilism - the theory of logic only leading to knowledge if the justification is reliable - is present in the argumentation process in terms of an experimental design that satisfies reliability aspects by repeated, coherent measurements and by supplying sufficient warrant and backings. Reliabilism furthermore drives wider scientific debates, resulting in the acceptance of only those theories and models that emerge from inquiries that can be repeated by other scientists and yield similar results. The tenet of coherentism – the notion that knowledge is secure when coherent with other forms of logical constructs – is evident in the conceptual knowledge that informs the inquiry to begin with, and that is a result of other logical constructs. It is also apparent in the broader scientific debate because new theories are only accepted if they are coherent with other accepted scientific theories and other scientific models and theories. Lastly, the theory of empiricism is essentially the process of scientific argumentation in scientific inquiry, in which reason is derived from observation.

Induction, deduction and abduction – three knowledge generative processes –are inseparable from scientific argumentation as they are embedded in scientific reasoning. Similarly, the hypo-deductive method is basically scientific argumentation itself, given that it is the process of the generation of hypotheses, based on observations, followed by the testing of these hypotheses, based on further observations.

Furthermore, argumentation in science supports the development of the more theoretical and philosophical aspects of science epistemologies, and is thus included in the *nature of science* concept. First, the application of the principles of *scientific argumentation* in an authentic science-inquiry learning context helps students to conceptualise science as a process of building and testing models and theories, as opposed to a view of science as a steady accumulations of facts about the world (Carey, Evans, Honda, Jay, & Unger, 1989; Driver et al., 1996; Lederman, 1992; Sandoval, 2003). Second, there is a positive relationship between the ability to conduct scientific argumentations and the acceptance of the constantly changing, dynamic nature of scientific knowledge consisting, as it does, of competing theories and a body of, sometimes contradictory, evidence rather than of absolute truth (Bell, 2000; Bendixen & Schraw, 2001; D. Kuhn, 1991; Songer & Linn, 1991). Third, scientific argumentation offers insight into the social negotiations that surround the development of scientific knowledge and, at the same time, provides a grounding to cognitive schemas that guide negotiation of wider social contexts (Duschl & Osborne, 2002). The interplay of social, political, economic and ethical aspects with the advancement of scientific knowledge is, most illuminated when the principles and processes of scientific argumentation are set in a socio-scientific context and students engage in activities that require *looking back* perspectives (Roberts & Gott, 2010; Thagard, 1994). Lastly, studying *scientific argumentation* can help to distinguish between cultural constructivism and epistemological relativism. Sociological constructivism implies that scientific research is influenced by ideology, power and commercial interest, but does not deny epistemological objectivity insofar as scientific knowledge is derived from the process of rational thinking (M. P. Jiménez-Aleixandre & Erduran, 2007). Epistemological relativism, on the other hand, refers to knowledge generative process that occurs in the minds of thinking people, individually or through social exchanges, knowledge is a subjective representation of a reality and therefore, relative to the knower (Deng et al., 2011). These two distinct parts of the discourse surrounding the development of scientific knowledge are depicted in Figure 5.3. Here the epistemologically objective aspects reside in the *Design* and *Scientific Justification* stages, which are derived from reason and logic. This sits in contrast to the b*roader socio-scientific discussion* stage which can be conceptualised as being founded on social relativist assumptions. (What this diagram does not show is how these social, economic and political factors influence scientific research in terms of power and funding that determines, what research will be carried out.) The idea of the possibility of holding multiple philosophical positions linked to the understanding of various aspects of scientific argumentations is confirmed by Glasson and Bentley (2000). Scientists' inconsistent positions, depending on whether they are viewing their practices from the *science process* or the *social practice* of science positions, here respectively correspond with the *Design* and *Scientific Justification* stages and the *Broader socio-scientific discussion* stages of Roberts' and Gott's model respectively. Then again, these two positions are not necessarily reflect multiple epistemic positions, rather with reference to the *science process* scientists take absolutist or realist positions and this position is their actual epistemic position. The other position in relation to *science practice* could arise from a sociological constructivist view, which acknowledges the influence of various interests on scientific research yet is not equated with epistemological relativism and does not deny objectivity.

Scientific argumentation is at the heart of the development of scientific knowledge and is therefore inseparable from the development of an informed view of science epistemology. The connection is summarised in Figure 5.4 using Gott's and Roberts' (2008) bulls-eye conceptualisations of concepts of evidence and claims.

In the diagram the shaded area refers to research design. According to the analysis above the shaded area indicates *science process* and the unshaded area the *social practice of science*. The philosophical underpinnings of the processes in these areas can be different – as described above. The outward pointing arrow shows on Figure 5.4 the *looking forward* direction of scientific argumentation. This is used in science inquiries, during which scientists set out the conditions in such a way that the data can be used as evidence to make a scientific claims. On the other hand the inward pointing arrow on Figure 5.4 indicates the direction one follows when assessing scientific information and must consider how ideas from all layers of the bulls-eye have been used in the construction of the claim.

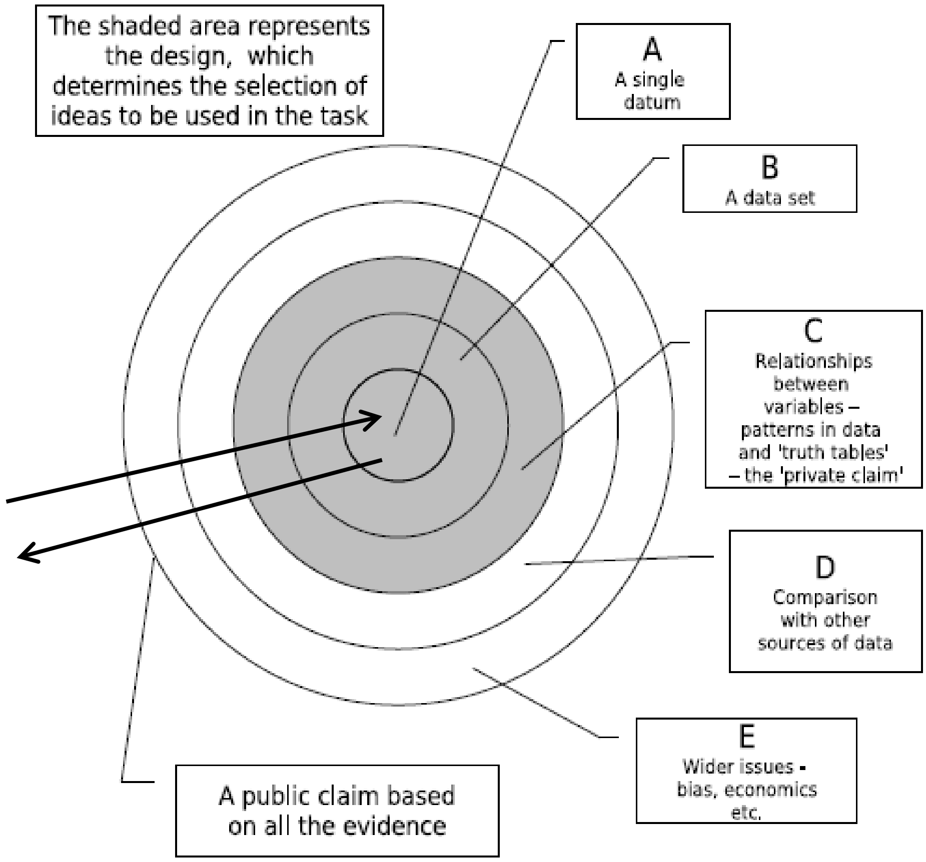


Figure 5.4: Concepts of evidence: bulls-eye conceptualisation (Richard Gott & Roberts, 2008, p. 30)

CHAPTER 6

Methods

Research questions and hypotheses

In the previous chapters, the pivotal role of the development of science epistemology in science education for an understanding of the power and limitations of scientific knowledge was discussed. An accurate understanding of scientific knowledge generating processes can guide decision making in science related issues in all aspects of life. The development of science epistemology and *scientific argumentation* are specifically-targeted areas of learning in New Zealand. The *New Zealand Curriculum* (Ministry of Education, 2007) provides direction about the levels of progression. According to these, students at all curriculum levels will develop an understanding about science in terms of knowledge development in discipline specific ways. The role of learning science is described as follows:

> "Science is a way of investigating, understanding, and explaining our natural, physical world and the wider universe. It involves generating and testing ideas, gathering evidence – including by making observations, carrying out investigations and modelling, and communicating and debating with others – in order to develop scientific knowledge, understanding, and explanations. Scientific progress comes from logical, systematic work and from creative insight, built on a foundation of respect for evidence." (Ministry of Education, 2007, p. 28)

This would imply the development of both science epistemology and *scientific argumentation* during the study of science subjects. As shown in Chapter 5 *nature of science* is relevant to the development of science epistemology, because it is the term used in science education to describe educational aims concerned with the development of science epistemology. Furthermore, there is a specific overarching strand assigned to the development of *nature of science* conceptions, meaning a progression in its conceptualisation is an expected outcome of science education. Additionally, the link between *scientific argumentation* and science epistemologies was shown making it therefore fair to assume that the development of concepts of *scientific argumentation* can be indicative of epistemological development. Therefore, it also appears reasonable to investigate these two areas in parallel to gain an insight into the development of science epistemology.

The main purpose of the present study was to investigate the effects of studying various science disciplines on the development of science epistemology in senior high school students over three terms of a science course. The research is necessarily quasi-experimental as random assignment of subjects to treatment groups and control groups was not possible since students cannot be randomly assigned to study, or not to study science. The quasi-treatment group comprised students studying science and quasi-control groups made up of students not studying science. Progression was measured in two distinct areas, *theory development* and *data collection*, the two variables identified by EFS. The secondary purpose of the present inquiry was to examine the progression of science epistemology through the senior years of studying science, in years 12 and 13. Third aim was to investigate the extent to which various science disciplines contribute to the development of science epistemology. Lastly, an analysis was conducted to identify the relationship between the completion of inquiry-type course work and science epistemology. Additionally the correlation between inquiry-type courses' assessment results and the advancement of epistemological views were examined.

The main research question concerning the development of science epistemology in relation to studying science is:

> *Does three terms of science study affect the development of science epistemology in Years 12 and 13?*

In a majority of high schools at Year 11 general science is a compulsory subject, therefore sampling quasi-treatment and quasi-control groups was not possible. Meaning the effect of studying or not studying science was not attainable. Year 12 and 13 students can specialise in the different science disciplines (biology, chemistry, physics, general science and earth science), undertake a general science course or elect not learn science at all. It was hypothesised that students who are undertaking the study of science will show a greater increase toward a more advanced science epistemological view compared to students not studying science. This hypothesis tests the assumption that science courses address the requirements set out in the curriculum.

The second research question is related to science epistemology development at different levels of study.

> *Does the levels of study (Years 12 or 13) affect the development of science epistemology?*

It was hypothesised that students undertaking science studies in Year 13 will be at and progress at a higher rate. This hypothesis was based on the assumption that epistemological orientation is age dependent it is supported by D. Kuhn (1991) and Mason and Scirica (2006) research that identifies a developmental sequence in the formulation of epistemological views, showing a progression from absolutist to a multiplist to an evaluative through the different stages of childhood to adolescence and early adulthood (Khishfe, 2012b).

A third research question explores the different science disciplines in relation to the dependent variable:

> *Does the study of different science disciplines impact differently upon the development of science epistemology?*

It was hypothesised that there would not be significant difference between students who learning different science disciplines. This hypothesis is consistent with Cavallo, Rozman, Blickenstaff and Walker's (2003) findings that compared *nature of science* views across science majors and did not find significant difference between their views.

Science courses are relatively flexible in New Zealand in that each school creates science courses and chooses an assessment program for these from several externally and internally assessed standards in each science discipline. Science courses can vary within a school as well - different classes studying the same scientific discipline at the same year level can undertake different courses, assessed by different Achievement Standards. While externally-assessed standards predominantly focus on science content some of the internally-assessed standards require students to carry out science inquiry. The relevant Achievement Standard titles are listed on page 55. Units involving the assessment of science inquiry are therefore appear to be especially relevant to the development of science epistemology.

The fourth research question then is this:

> *Does the completion of internally-assessed, inquiry-type coursework affect the progression of science epistemology and scientific argumentation skills?*

It was hypothesised that completion of internally-assessed, inquiry-type course work would support the development science epistemology.

Finally, the extent to which the survey results and the inquiry-type NCEA assessment results correlate the last research question is:

To what extent do students' NCEA results correlate with students' epistemic views and scientific argumentation skills?

Some correlation is expected to be observed between NCEA results and the development of science epistemology. Analysis of variance was used to test the first three hypothesises and correlation analysis was used to test the fourth hypothesis. The procedure is explained fully in *Methods* section.

Ethical considerations

The data collection began when approval from Victoria University's Ethics Committee was granted. Prior to data collection, informed consent forms were obtained from the participating institutions' Boards of Trustees, participating teachers, students and their parents (if they are under 16). This was done in accordance with the Principles Relating to Research Participants 3.2 of NZARE Ethical Guidelines (New Zealand Assossiation for Research in Education, 2010), which states "Informed consent. Before participants make a decision about their involvement in a project they need to be given a clear description of why the research is being undertaken, what it involves, how it will be reported, and the extent of public availability." (p. 6)

The research design required the use of closed ended questionnaire, so that analysis of variance can be conducted. This in turn also reduced the time requirement for administrating of the questionnaire, therefore minimising the impact on learning time. The timing of the administration of the instrument at both stages was coordinated with the teachers and heads of departments to avoid interference with assessment commitments. The research procedure therefore is in accordance with the General Principles 2.1 of NZARE Ethical Guidelines (New Zealand Assossiation for Research in Education, 2010), which states "Educational researchers should seek at all times to avoid harm and do good." (p. 5)

Although the research cannot be fully anonymised due to the need to match questionnaires to NCEA results, the confidentiality of the results was ensured by restricting the research data to the researcher and the supervisor. All identifying information was destroyed. The participants had the right to withdraw their data until November 2015.

Research paradigm and experimental design

A quantitative research paradigm was used to establish the relationships between the aforementioned variables – the study of various science disciplines and the development of scientific epistemology. Quantitative research is based on post-positivist philosophical assumptions and is thus a deterministic philosophy in which causes determine effects of outcomes (Creswell, 2013). The research is informed by post-positivist philosophical assumptions and based on careful observations and measurements of reduced, small, discrete set of variables to test hypothesise derived from the research questions. Quantifiable observations and measurements are paramount for this type of research. The starting point of the research is a theory and the inquiry either supports or refutes that theory (Creswell, 2013). A quasi-experimental design rather than a true experimental one was employed because it was not feasible to randomly allocate participants to treatment and control groups.

Participants

The participants in the research where 785 (n=785) students from ten high schools in the Wellington region and one in the Waikato region. The first yielded 695 responses and the second 334 responses. The treatment group (n=666) comprised year 12 and 13 students undertaking science courses, whereas the control group (n=119) consisted of those not studying science at the same year levels. For the analysis only those participants' results were used whom completed the survey in both rounds.

Procedure

The analysis comprised three main parts: pilot study, instrument calibration and data analysis. The aim of the first stage of the research was to develop the instrument. This involved three rounds of pilot-testing to refine the items, which included eliminating repetitive and ambiguous statements. This process reduced the number of items from 88 to 34 (see Appendix 2 for the final version of the instrument). After the pilot study the main study began in Term 1, when the first round of responses was collected. The instrument validation was conducted on the results gained from the first round, which included an exploratory factor analysis (EFA) and Rasch analysis. After the second round data was collected, analyses of variance were completed with the use of variables identified by EFA and ratio scaling produced by Rasch analysis.

The instrument used for the measurement of dependent variable – development of science epistemology – was specifically developed for this study. The new instrument consisted 34, closed-end items divided into two sections: *nature of science* (16 items) conceptions and *scientific argumentation* (18 items). The levels science epistemic views were demonstrated by responses to the two separate sets of agree/disagree statements.

Once the final version of the instrument was established the first round of the data collection proceeded during term 1, 2015. The first round yielded 694 responses from the eight participating schools.

To determine whether the instrument properly captured these attributes or would actually measure more than two traits - in other words the dimensionality of the instrument - was identified by exploratory factor analysis (EFA). EFA, furthermore, establishes how strongly each item is associated with each fit into these dimensions (Neumann et al., 2011). The originally intended independent variables, *nature of science* and *scientific argumentation*, were reformulated as a consequence of EFA and lead to two new variables: *theory development* and *data collection*. From this point forward the development of science epistemology was examined in terms of students' progression on these variables. The process of the identification of the new variables is explained in detail in the *Results* section.

The agree/disagree responses were recorded as ordinal data and usually not scaled to the same magnitude. Therefore, parametric analysis methods cannot be used for further analysis. The factor scores gained from the EFA were then subject to multiple regression analysis – or Rasch analysis - to convert the ordinal data gained from agree/disagree responses into ratio scaled data and to confirm the dimensionality of the instrument identified by the EFA. In order to scale the ordinal data to interval scales, Rasch analysis was employed. This calibration process is described by Neumann et al. (2011) as follows: "Based on observed response patterns, Rasch models produce item parameters and person parameters that are of a ratio level of measurement. This allows appropriate comparisons of students and items by comparing quantitatively equivalent intervals." (p. 1382). Both dimensionality and calibration was carried out on the data collected in the first round of the main study. It would have been ideal to carry out these analyses on the data collected at the pilot-testing stage but there were not enough fully completed surveys to allow a reliable statistical analysis at that stage. The calibration process is explained the *Results* section.

The main study involved the comparison of responses obtained from the two rounds. The progression in science epistemology views were determined by the survey scores. A quasi-experimental design was implemented in this study, as random assignment of subjects to treatment and control groups was not possible. A random sampling was not possible therefore, the effect of extraneous variables cannot be ruled out and the samples were not necessarily representative of the population as pre-existing groups, science students and students not studying science were tested in this research (Creswell, 2013; Shadish, Cook, & Campbell, 2002).

The precise date of survey completion could not be completely controlled as the schools had to fit this task into their learning programmes. The second round was completed towards the end of Term 3. This was affected by unforeseen factors, for example a number of Year 13 students had left school by then. This and other factors, such as assessment pressures contributed to a significantly lower response rate in the second round. In all of the participating schools, the Head of Sciences organised the administration of the survey. Because organisation of non-science learners was often beyond their influence, this resulted in the quasi-control groups being a lot smaller compared to the quasi-treatment groups. The a sample size of the main study as a consequence comprised 200 students in the quasi-treatment group – science students - and 38 students in the quasi-control group – students not studying science.

The comparison of the results yielded from the two rounds involved several repeated-measures analyses to answer the research questions and to determine the individual and combined effects of the independent variables by the use of an analysis of variance (ANOVA) analytical tool using SPSS for Windows software.

Four independent variables were investigated: studying or not studying science, year level (12 or 13), studying or not studying various science disciplines (biology, chemistry and physics) and the completion of inquiry-type course work. The repeated-measures analyses of variance were implemented separately for the four dependent variables.

The surveys were completed twice; first in Term 1 and second late in Term 3, therefore the effect of the completion of the science course could be measured. The research was designed to determine the effects of studying science on *theory development* and *data collection*, the two dependent variables identified by EFS. For this repeated- measures analyses were employed with time (term 1 vs. term 3) as within-subject factor and treatment (science students vs. no science study) as a between –subject factor for each dependent variable separately. Further analysis was conducted to identify the effect of the level of study on the two dependent variables. Two repeated–measures analysis was carried out with time (term 1 vs. term 3) as within-subject factor and year levels (year 12 vs. Year 13) as a between-subject factor. Although four Year 11 students participated in the study, as accelerated students completing Year 12 science courses, given the small sample sizes these results were emitted. The third analysis was employed to determine the effect of inquiry-type courses - these are assessed by specific internally-assessed standards - on the development of *data collection* and theory *development variables*. Again repeated-measures analyses were conducted with time (term 1 vs. term 2) as within-subject factor and inquiry-type course completion (science inquiry vs. no science inquiry completion) as between-subject factor. In this part the completion of the following internally assessed Achievement Standards were analysed in relation to the two dependent variables separately:

- AS91153 2.1 Carry out a practical investigation in a biology context, with supervision
- AS91601 3.1 Carry out a practical investigation in a biological context, with guidance
- AS91161 2.1 Carry out quantitative analysis.
- AS91387 3.1 Carry out an investigation in chemistry involving quantitative analysis.
- AS91168 2.1 Carry out a practical physics investigation that leads to a non-linear mathematical relationship
- AS91521 3.1 Carry out a practical investigation to test a physics theory relating two variables in a non-linear relationship.

The last analysis investigated the correlation between inquiry based assessment results and epistemic views demonstrated by theory *development* and *data collection* scores. A Pearson's correlation analysis was run to identify the extent to which the inquiry results correlated with independent variables' scale locations and the calculated correlation coefficients determined the strength and the direction of the correlation.

Instrument development

Quantitative instrument

A new closed-response instrument was designed for this research. A new instrument was needed because there are no closed-ended instruments that measure these two central facets of science epistemology – *nature of science* conceptions and *scientific argumentation* skills. Furthermore, there is a general need for rigorously evaluated closed-response instruments to empirically test hypotheses regarding the development of science epistemologies in larger samples (Neumann et al., 2011). The final version of the instrument used in the present study comprised 34 items. These agree/disagree statements were listed in two distinct sections: *nature of science* and *scientific argumentation*. The *nature of science* section consisted 16 items and the remaining 18 items made up the *scientific argumentation* section.

Item development

The items for the first version of the instrument were developed based on existing instruments using materials from F. Abd-El-Khalick and Akerson (2004); Eastwood et al. (2012); Glaesser, Gott, Roberts, and Cooper (2009); Hind, Leach, Ryder, and Prideaux (2001); M. Jiménez-Aleixandre, Gallástegui-Otero, Eirexas-Santamaría, and Puig-Mauriz (2009) Deng et al. (2011); Lederman et al. (2002) (See the references for each items in Appendix 1).

These original instruments are open-ended instruments in which authentic student responses cited. The authentic responses were coded and grouped in the original research according to the positions they represent towards aspects nature of science or the level of understanding of coordination of scientific evidence in scientific argumentation. These authentic student responses were used for the new instrument as agree/disagree statements. This item development method is similar to Chen's (2006) except that in his study authentic responses were gathered during the pilot study, unlike in this case where the authentic responses were selected from other studies. The advantage of using authentic student responses that is reduces the ambiguities of statements constructed by experts. This has been a major criticism of previous closed-ended instruments (Aikenhead & Ryan, 1992; Chen, 2006; Deng et al., 2011) since the use of closed-ended items are based on the assumption that the participants perceive and interpret the statements in a manner similar to that of the instrument developers. Additionally, the assumption that the participants and the developers agree or disagree with statements for the same reasons further threatens the validity. While these issues needed to be considered in the use of a closed-ended instrument, through the use of authentic students statements the likelihood of misinterpretation is reduced (Chen, 2006).

The first version of the instrument was divided into two distinct sections, a *Nature of science* and a *Scientific Argumentation* section consisting of 50 and 48 items, respectively. The *Nature of science* section was further divided into sub-sections according to the main tenets of *Nature of science* such as science is empirical (7 items), tentative (6), distinction between hypothesis, theory and law (7), myth of scientific method (5), experimentation (10) and controversy in science (15).

The *scientific argumentation* section was further divided into 5 sub-sections, each describing a scenario with statements referring to these scenarios. The scenarios were designed to assess students' understanding of the creation of conditions to produce scientific evidence (7 + 6 items), assessment of quality of data (9 + 6 + 10) and use of evidence (10).

Pilot Rounds

The first round of pilot testing began on 19th of November 2014 after the Ethics approval was granted. This date restricted the availability of subjects due to courses ending by then at both senior high school and university level. The aim of the first round was to reduce the number of items by excluding confusingly worded, too obvious and repetitive items. The selection of the sample for the pilot study was based on availability and volunteering from both course controllers and university students.

The first pilot round was completed by 24 (n=24) Bachelor of Teaching students and a hard-copy version was used. Given the small sample size, quantitative analysis methods, such as PCA or EFA could not be carried out. As a consequence of the high number of items a great proportion of respondents (81.5%) did not answer all of the questions. Unsurprisingly, a majority of the comments in the feedback section suggested the reduction of items and the elimination of repetition.

The second pilot round was sent out to three Trimester 2 Science Faculty students. These participants received an electronic version of the survey created in Google Docs. The second version was completed by 29 (n=29) mainly undergraduate students. Again, this round only yielded 20.7% fully completed surveys due to its length and repetitive nature. The repetition was mainly was due to the inclusion of various positions in relation to a *nature of science* conception. For example Part B Item 3 "Scientific knowledge does not change once it established" and Part B Item 4 "Scientific knowledge can change given new evidence and interpretations". Some of the positions were also stated in several different ways, such as Section B, Item 1 "Scientific knowledge is certain and set in stone" and Part A Item 1 "Once scientific theory is proven then it becomes a scientific fact and does not change". Some of these repetitive statements were still included to identify the ambiguously worded, confusing and too obvious statements.

For the third pilot round all items were revisited and ambiguous or repetitive statements were deleted. In the new version the different sections of *nature of science* were merged and the statements shuffled, so any one statement would not be obviously indicative of another statement from the *nature of science* theme. The number of statements referring to *nature of science* conceptions was reduced to 17. In the *scientific argumentation* section a fourth sub-section was completely eliminated as it appeared to be too wordy and uninteresting. Furthermore, the number of statements were reduced in all other sections resulting in 18 (2+8+4+4 per sections) items. Although a larger number of items would have increased the reliability of the survey, by reducing the number of items the likelihood of full completion is increased and administration became more manageable. This was especially a pivotal factor in terms of ethical considerations; the administration of the survey was intended to cause the least possible disruption to students' learning programmes.

The third pilot round completed between 5 and 27 of December 2014 yielded 22 (n=22) fully completed responses. Based on the responses the statements were again revised and few changes were made to improve their clarity. See the finalised version of the survey in Appendix 2.

The final version of the instrument

The final version of the instrument consisted of substantially fewer items then the original version. As mentioned before, this was essential, in order to both increase the chance of full completion and reduce the impact of the research on the participating schools, teachers and students. This also resulted in a reduction of the reliability of the instrument as - especially in the *Nature of science* section – there were only a few items relating to each aspect of the target aspects of *nature of science*. Table 6.1 shows the items from the *nature of science* section and the *nature of science* tenets which they sought to measure.

The first 16 items relate to *nature of science* conceptions. These are listed in Table 6.1 with reference to the *nature of science* tenet that is measured. The second section's 18 items measure levels of understanding of *scientific argumentation*. In the second section the first three scenarios' 14 items relate to the conditions of scientific experimentation that can yield scientific evidence. The last scenario's four questions relate to the accumulative nature of scientific evidence.

Table 6.1 *Nature of science* section's items in relation to *nature of science* tenets

Item	*Nature of science* tenets
1. Scientific theories are always based on direct observations.	Scientific knowledge is empirical, based on observations (and inference)
2. Scientific theories can change given new evidence or interpretations of data.	Scientific knowledge is tentative
3. Scientific theories based on indirect observations are less valid than those based on direct observations.	Scientific knowledge is empirical, based on observations (and inference)
4. The scientific method is a method of testing hypotheses.	Scientific method
5. Any process that involves the collection of data is an experiment.	Experimentation
6. The difference between a scientific law and a scientific theory is that a law has been proven to be true, but a theory might still be proven false.	Difference and relationship between scientific theories and laws
7. Scientific knowledge is solely established by experiments.	Experimentation
8. If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change.	Scientific knowledge is tentative
9. Scientific method always follows the same steps in the same order.	Scientific method
10. Experimentation does not necessarily require manipulation of variables.	Experimentation
11. If sufficient data were available there would be no controversy over scientific theories.	Scientific knowledge is theory laden
12. Scientists know that they have the right answer to a research question if they have followed the scientific method.	Scientific method
13. Different scientists may make different interpretations of observations and experiments.	Scientific knowledge is theory laden
14. A scientific theory or hypothesis cannot be proven to be true.	Scientific knowledge is tentative
15. Scientific theories are fact-based and not influenced by scientists' opinions.	Scientific knowledge is theory laden
16. When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data.	Scientific knowledge is theory laden

Instrument calibration results

Exploratory factor analysis (EFA)

To reduce the number of variables to more general underlying dimensions EFA was carried out. A consequence of the use of a 34-item survey is that all of these items are considered as variables. EFA attempts to bring inter-correlated variables together to create a reduced number of more general, underlying variables (Nerbonne, 2014). More specifically, the goal of factor analysis is to reduce "the dimensionality of the original space and to give an interpretation to the new space, spanned by a reduced number of new dimensions which are supposed to underlie the old ones" (p. 254; Rietveld & Van Hout, 1993).

The 34 items were included as variables in an explanatory factor analysis with direct oblimin rotation. The factors displayed on a scree plot indicated two factors before the break point. This method, developed by Cattell (1966), is based on a visual exploration of eigenvalues, which are represented in descending order, displaying the magnitude of the eigenvalue associated with each factor. The factors before the last significant drop are extracted, establishing a breaking point which essentially divides the major and the minor factors (Ledesma & Valero-Mora, 2007).

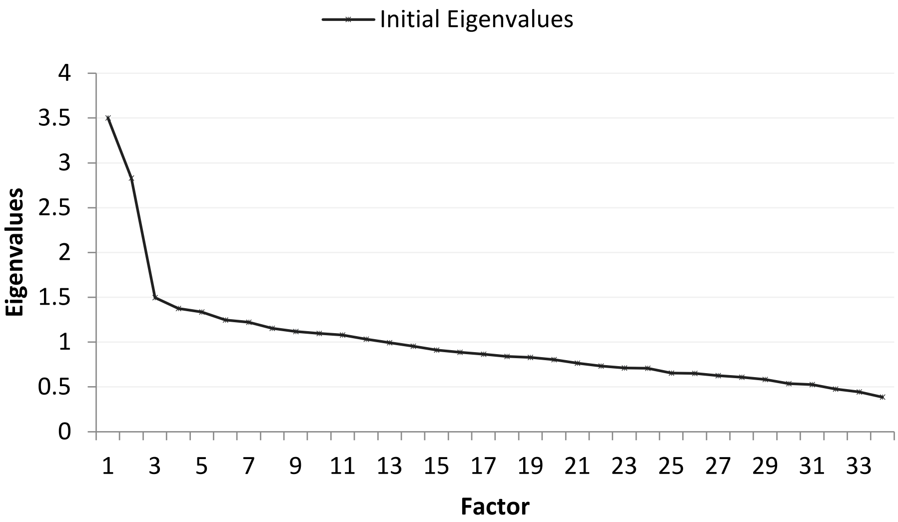


Figure 6.1 EFA scree plot first extraction shows two factors before the last significant drop, which then were extracted.

Although the two extracted factors only accounted for 14.9% of the variance, in the data, the large sample size compensates, to some extent, for the low communalities.

The employment of oblique rotation allowed the factors to correlate, however the data showed no correlation between the first two factors; r=0.05. This suggests that the two factors constitute the latent variables.

A subsequent factor analysis was carried out forcing two-factor solutions. This process helps to refine the original analysis and yield a more accurate latent structure.

A principal component analysis (PCA) was also carried out as a check on the factor analysis. It revealed a similar underlying dimensionality to that of factor analysis. The strong agreement between the results of the two different analyses confirms the structure of the underlying dimensions shown. The similarity of the results is illustrated in Table 6.2.

Table 6.2 The similarities between eigenvalues for individual items on components 1 and resulted from PCA and eigenvalues for individual items on factors 1 and 2 yielded from EFA.

PCA Structure matrix components			**EFA Structure matrix factor structure**		
Item number	Eigenvalues		Item number	Eigenvalues	
	1	2		1	2
12	0.558		12	0.511	
27	0.520		27	0.465	
16	0.503		16	0.453	
28	0.499		8	0.440	
26	0.473		28	0.439	
15	0.453		26	0.401	
11	0.445		15	0.394	
33	0.433		11	0.379	
8	0.429		33	0.357	
1	0.421		1	0.354	
7	0.395		7	0.332	
9	0.384		9	0.320	
23	-0.323		23		
31	0.318		31		
3			14		
14			3		
5			5		
13		0.577	22		-0.529
22		0.574	13		-0.516
24		0.546	24		-0.489
2		0.494	2		-0.422
34		0.476	34		-0.417
6		-0.414	6		0.339
4		0.385	4		-0.317
19		0.38	29		-0.312
29		0.379	18		-0.308
18		0.361	19		-0.308
32		0.36	32		
30	0.302	-0.338	30		
17		0.322	17		
20		0.321	21		
21		-0.317	20		
25			25		
10			10		

In order to identify the underlying dimensionality of the variables the items that loaded on either factor were matched with the statements from the instrument. This is shown in Table 6.3. The result of this analysis was a rotated component matrix consisting of two factors that again accounted only for 13.78% of the variance. A further three analyses were run, eliminating variables that did not load on either factor or which loaded similarly on both factors, yielding the structure.

Table 6.3 Refined structure matrix, Eigenvalues for each retained items on factors 1 and 2 with the item statements

Factor			
Item number	Eigenvalues		
	1	2	**Survey items**
12	0.544		Scientists know that they have the right answer to a research question if they have followed the scientific method.
16	0.475		When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data.
8	0.450		If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change.
27	0.416		We can be more confident in Group A's result because two of their measurements agree.
28	0.415		We can be more confident in Group A's result because one of their measurements is the same as their average.
11	0.408		If sufficient data were available there would be no controversy over scientific theories.
26	0.388		Group A's conclusion, "the more fertiliser you add the better plants grow", is supported by the two groups' combined data.
15	0.387		Scientific theories are fact-based and not influenced by scientists' opinions.
33	0.342		Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus' remains.
7	0.331		Scientific knowledge is solely established by experiments.
1	0.326		Scientific theories are always based on direct observations.
9	0.318		Scientific method always follows the same steps in the same order.
13		0.596	Different scientists may make different interpretations of observations and experiments.
22		0.526	The reliability of the data could be improved by repeated measurements in both groups' investigation.
24		0.510	The validity of these experiments cannot be decided because there is no information about how other variables were controlled.
34		0.409	The individual pieces of evidence one-by-one are not very relevant; rather the accumulation of these pieces of evidence gives more reliability to the claim.
2		0.388	Scientific theories can change given new evidence or interpretations of data.
29		0.322	We can be more confident in Group B's result because the range between the largest and the smallest measurement is less.

The EFA did not clearly confirm the structure set out during the design of the instrument as both factors included items from both the *Nature of science* and *Scientific argumentation* sections. Since the variables did not clearly load on the two factors in alignment with the two theoretical construct driving the research – *nature of science* conceptions and *scientific argumentation* - this suggests that *nature of science* and scientific argumentation might not be coherent constructs.

Discussion: EFA result

The survey was divided two distinct section, *nature of science* and *scientific argumentation*. The individual items were generated by the use of existing instruments. However, the EFA revealed two uncorrelated factors. Each of the factors consisted statements from both sections of the survey, indicating that the originally intended constructs might not be coherent structures, rather epistemological development is formulated around two different latent variables demonstrated by above correlated conceptions. On the first factor items 26, 27, 28 and 33 were from *scientific argumentation* section and the rest, items 1, 7, 8, 9, 11, 12, 15 and 16 from *nature of science* section. On the second factor items 13 and 2 were form *nature of science* section, while the other items, 22, 24, 29, 33 and 34 from the *scientific argumentation* section.

A qualitative analysis of the factor items lead to the conceptualisation of the structure and the common theme of the items loading on the factors. The retained items loading on the two factors appear to be fitting with dimension of knowledge as explained in Chapter 5. These dimensions form and realist perspective is as shown in Table 6.4.

Table 6.4 The dimensionalities of knowledge from realist perspective

Nature of knowledge	**Certainty of knowledge**	Knowledge is interpreted and negotiated based on empirical evidence at hand. Knowledge is stable as long as no refuting evidence surfaces.
	Simplicity of knowledge	Complex, accumulative, knowledge is evolving based on multiple evidence.
Nature of knowing	**Justification of knowing**	Knowledge requires justification and the justification is based on the evaluation of the strength of the evidence.
	Source of knowledge	Derived from evidence and reason, it is constructed, endures time but fallible. Experts advance it but it needs to be critically evaluated.

The concepts represented in the items loading on the first factor are related to the following dimensions: knowledge is interpreted and negotiated based on empirical evidence at hand; knowledge is stable as long as no refuting evidence surfaces; it is complex, accumulative; it is evolving based on multiple evidence; derived from evidence and reason and it is constructed; therefore while it endures time, it is fallible. The items loading on the second factor primarily associated with the concepts of the justification of knowledge dimension, which from a realist position means that knowledge requires justification and the justification is based on the evaluation of the strength of the evidence. It also related to the concept of complex, accumulative nature of knowledge that is evolving based on multiple evidence.

The latent variable that underlies the first set of indicators it appears to be in relation to the ways in which scientific evidence leads to the development of a scientific theory. These stamens are related to conceptions about how theory is derived from empirical data and includes concepts such as how scientific theories are partially based on empirical data, but inferences are also made (items 1, 7), theory is based on multiple scientific evidence that derived from experimentation (item 7), theories are subject to change (items 8, 11 and 12), scientists formulate their theories based on existing theories (items 11 and 16) and various scientific methods can yield scientific evidence (items 12 and 9). Although items 26, 27 and 28 loaded on this factor during this process of qualitative analysis of the EFA results they did not appear to be fitting closely conceptually with the other items, therefore they were eliminated. Item 1 was also eliminated from the final analysis as 96.7% of the responses were correct; therefore it appeared to be too self-evident and unchallenging.

The items loading on the second factor appeared to be concepts relating to the experimental conditions required to set to increase reliability and validity of the investigation to yield data, which then can be used as scientific evidence. These concepts include reliability (items 22, 34 and 29), validity (item 24) and scientific theories are based on an interpretation of scientific evidence and it is subject to change based on emerging new evidence (item 2).

Consequently, the conceptualisation of first factor as the intellectual process surrounding the generation of scientific theory based on evidence. The second factor was perceived as ideas associated with the creation of conditions that yield scientific evidence. The factors, therefore, are identified as *scientific theory development* for the former and *data collection in science inquiry* for the latter.

The first factor, *scientific theory development*, refers to a latent variable concerned with conceptions relating to the process of testing to a theory with scientific evidence. This includes concepts such as the tentative and theory-laden nature of scientific knowledge, scientific knowledge mostly building on observations and inference being used in the case of unobservable phenomena.

The second factor, *data collection in science inquiry*, refers to an understanding of the suitable conditions that affect the strength of scientific evidence. This is also consistent with the *concept of scientific evidence* as argued by R Gott and Duggan (2007) including ideas of experimentation design that underpins the reliability and validity of investigations, the purpose of controlling variables, sampling, accuracy of measurements and generalisability of the findings (R Gott & Duggan, 2007).

There appears to be certain overlap between the dimensionalities of epistemological development shown in Table 6.4 and the item factor loadings, which suggest that these dimensionalities possibly better capture the epistemological development, compared to *nature of science* and *scientific argumentation* conceptions. This could be further investigated with an instrument especially designed to assess the development of these dimensionalities.

Rasch analysis

Following the EFA the data for of the items loading on each of the two factors were calibrated to measurement variables using Rasch analysis. The purpose of Rasch analysis is to first convert a series of mutually correlated ordinal variables into a single variable with interval properties. This is a necessary step before using parametric analysis, such as analysis of variance, which requires the dependent variable to have interval properties. The Rasch model, one of the most frequently-used item response theory models, generates a parameter for each item reflecting the difficulty of that item on an interval scale. This parameter, in conjunction with a parameter that estimates each respondents' ability determines the probability of a correct response (An & Yung, 2014).

Table 6.5 shows the results of the Rasch analysis.

Table 6.5 Item parameters for *Theory development* and *Data collection* variables

Theory development variable		
Item number	Parameter	Item statements
7	-0.95	Scientific knowledge is solely established by experiments.
16	-0.71	When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data.
8	-0.48	If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change.
15	-0.47	Scientific theories are fact-based and not influenced by scientists' opinions.
11	-0.33	If sufficient data were available there would be no controversy over scientific theories.
12	-0.31	Scientists know that they have the right answer to a research question if they have followed the scientific method.
9	-0.08	Scientific method always follows the same steps in the same order.
33	0.02	Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus' remains.

Data collection variable		
Item number	Parameter	Item statements
2	-3.69	Scientific theories can change given new evidence or interpretations of data.
22	-1.56	The reliability of the data could be improved by repeated measurements in both groups' investigation.
24	-0.90	The validity of these experiments cannot be decided because there is no information about how other variables were controlled.
34	-0.46	The individual pieces of evidence one-by-one are not very relevant; rather the accumulation of these pieces of evidence gives more reliability to the claim.
29	1.03	We can be more confident in Group B's result because the range between the largest and the smallest measurement is less.

Main study

Analysis of variance

A series of analyses of variance (ANOVA) were carried out to find out whether or not the mean scores for the Rasch variables corresponding to each factor varied significantly on the basis of participation, or not, in science courses. Further ANOVAs were used to estimate the effects of the level of study, the study of different science disciplines, and the completion of inquiry-type course work on these dependent variables.

Differences between science students' and non-science students' progressions

> *Does three terms of science study affect the development of science epistemology in Years 12 and 13?*

To identify the effects of studying science on the two studied variables, *theory development* and *data collection*, repeated-measures analyses of variance were conducted with time (Term 1 vs. Term 3) as the within-subjects factor and treatment (science study vs. no science study) as the between-subject factors for each dependent variable separately.

For the *theory development* variable there were 200 science students in the sample and 37 students not taking science. Figure 6.2 shows the scale location change over time on this variable for the two groups of students. Science students had a significantly higher mean scores for theory development, $F(1, 235)= 13.03$, $p < .001$. There was no significant main effect of time; $F < 0$; nor significant interaction between time and studying/not studying science; $F(1, 235) = 1.351$, $p = .246$. This means that, although science students had a significantly better understanding of the concepts associated with theory development, participation in science courses did not contribute to the development of these conceptions.

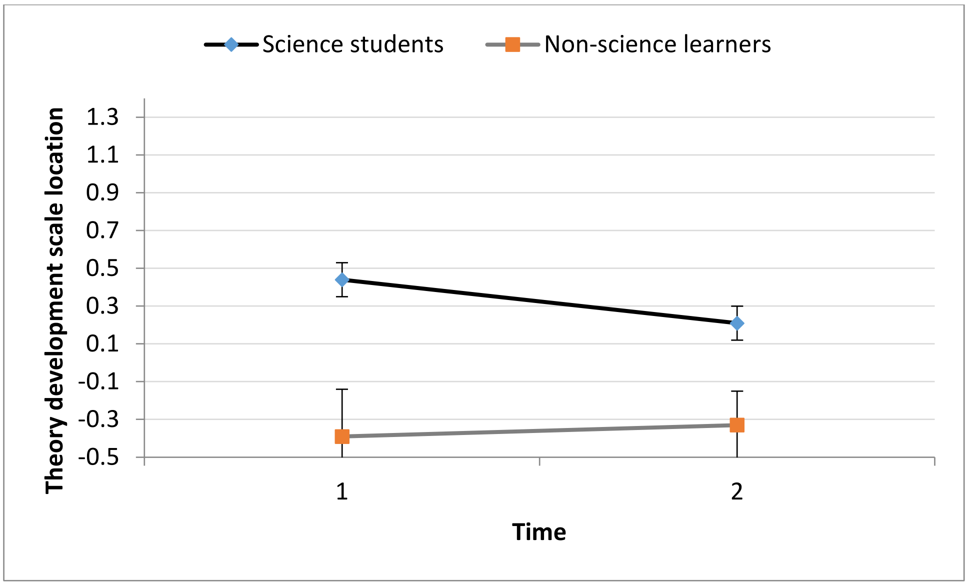


Figure 6.2 Scale location for the theory development variable in Term 1 and 3 for the science students group (n = 200) and students not learning science (n=37)

For the *data collection* variable the science learners and non-science learners' group sample size was 197 and 38 respectively. The sample sizes varied as the only those responses were selected, which had been completed both times, Term 1 and 3.Those, incomplete surveys, that had either first or second sets fully completed were still used, resulting in a variation of the sample sizes.

Figure 6.3 shows the change of scale location for *data collection* variable over time for between time points for science students and non-science learners. As for the case of the *theory development* variable, science students had significantly higher mean scores; $F(1, 233) = 21.08$, $p < .001$. This variable was different compared to the first one as the decline over time was significant; $F(1, 233) = 4.59$, $p = .033$. However there was no significant interaction between time and studying /not studying science: $F < 1$.

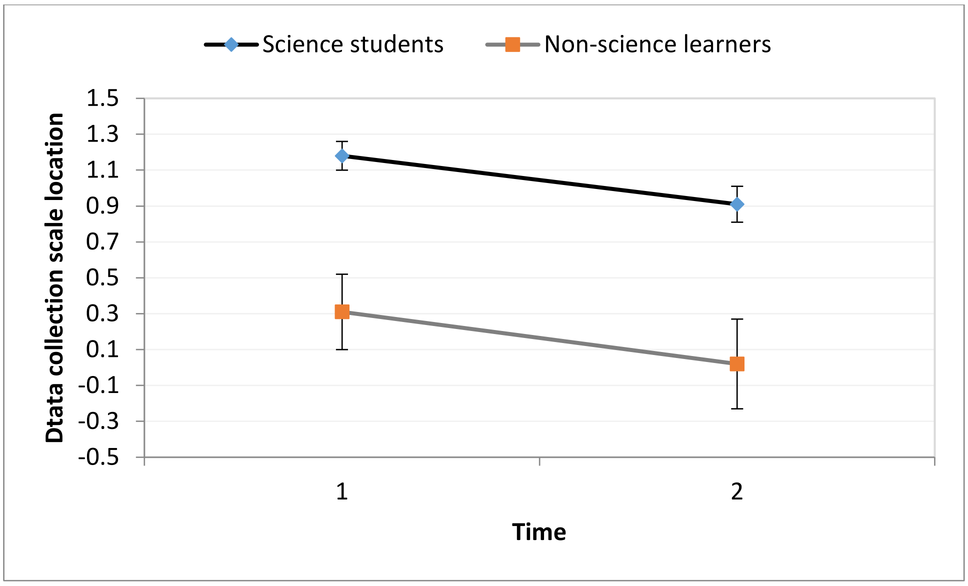


Figure 6.3 Scale location for data collections in Term 1 and 3 for science student group (n = 197) and students not learning science (n=38)

Discussion: Difference between science students and non-science learners' progression over time

The statistically higher scores for science students compared to non-science learners and no significant change over time means that, although science students had a significantly better understanding of the concepts associated with *theory development*, participation in science courses did not contribute to the development of these conceptions. The difference between the two groups 'scores could be indicative of varying dispositions and understanding of concepts associated with *theory development*. In other words, students who have better understanding of these concepts might be more likely to choose science subjects. The findings are contradictory to the hypothesis that students studying science will develop towards a more advanced epistemic view. The significant main effect of group indicates that the difference between the two groups' scores reflects a positive correlation between studying science and science epistemology conceptions, suggesting that science students have a higher level of understanding of these epistemic concepts.

The pattern of the data for *data collection* was similar to that for *theory development*: The science learners' group had significantly higher scores at both times of measurement compared to those not studying science. A difference, however, was that, scale locations for *data collection* declined significantly over time, rather than remaining static, as they did for *theory development*. This refutes the hypothesis that students' epistemological development is supported by studying science for NCEA. Although, there was no significant interaction between time and studying/not studying science – which is indicative of a similar decline among the two groups – the interaction cannot be fully out ruled, however. The sample size of the non-science learners was very small compared to that of science students', therefore gaining a statistically significant interaction result is problematic. The interaction between groups and time could be further investigated.

Again, the higher scores for science students compared to students not studying science could be attributed to that students with a better understanding of concepts associated with the processes of science knowledge development are more likely to choose science subjects. A causal relationship between studying science and change in science epistemic views cannot be established, despite the fact that science students had significantly higher scores in both of the investigated aspects of science epistemology.

For both dependent variables, the science learners' group had significantly higher scores at the first measurement time point indicating that science students have a more advanced epistemic view in both areas compared with students not studying science. The lack of significant change over time as a consequence of studying science suggests that science learning does not have a positive effect on the development of the studied variables. Therefore, the higher initial score could mean that more informed science epistemology increases the probability of taking science subjects. The decline in students' *data collection* scores over time indicates that both groups of students initially had a better understanding of data collection concepts at the start of the year, which apparently diminished during the year. Further plausible explanation for the lack of improvement science students' scores is that the *theory development* variable comprises ambiguous concepts funded on philosophical positions; therefore the study of science could cause confusion, unless the philosophical underpinnings are addressed by explicit instruction (F. Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick et al., 1998; Eastwood et al., 2012; Khishfe, 2012a, 2012b; Lederman, 2007; McDonald, 2010; Reneé S. Schwartz et al., 2004). Explicit *nature of science* instruction is not a common practice in New Zealand schools (Hipkins, 2012; Hipkins & Barker, 2005) Similarly, the conceptions about data collection has to be addressed directly (Driver, Newton, & Osborne, 2000; R Gott & Duggan, 2007; R Gott & Johnson, 1996; Richard Gott & Roberts, 2008; Roth, 2004; Jim Ryder, 2001, 2002; Salter & Atkins, 2013; Sandoval, 2003, 2005; Sandoval & Millwood, 2007). Investigative skills are generally addressed in most schools and there are numerous resources to support teaching and learning in regard. Most text books used in schools include a chapter about science investigation.

These inquiry-type units are included in all science disciplines, and skills are assessed against internally-assessed Achievement Standards. The decline of science learners' scores between Term 1 and 3 could be attributed to the fact that in many schools these inquiry-type units are taught in Term 1 and these conceptions can fade during the year, if not reinforced.

Differences between year levels

Does the levels of study (Years 12 or 13) affect the development of science epistemology?

Two repeated-measure analyses of variance were undertaken to identify any changes associated in the two dependent variables (*theory development* and *data collection*) with science learning at different year levels. Both analyses of variance had time (Term 1 vs. Term 3) as a within-subject factor and year level (Year 12 vs. 13) as a between-subjects factors. It is important to note here that, although Year 11 students participated, these students were accelerated students completing Year 12 science courses, whilst in other learning areas they were taking Year 11 courses.

Figure 6.4 and 6.5 shows the change of scale locations over time for *theory development* and *data collection* variables at the two data collection points for each year level. None of the observed changes were statistically significant, meaning that no significant differences between the levels in terms of development of science epistemology over time were evident. Sample sizes were 4 at Year 11, 91 at Year 12 and 104 at Year 13 levels for *theory development* and 4 at Year 11, 89 at Year 12 and 103 at Year 13 levels for the *data collection* variable. For *theory development* there was no significant main effect time; $F < 1$, and no significant main effect of year level; $F < 1$, and no significant interaction between time and year level; $F (2, 196) = 1.155$, $p = .317$ Similarly in the case of the *data collection* variable there was no significant main effect of effect time; $F < 1$, no significant main effect of year level; $F < 1$, and no significant interaction between time and year level; $F < 1$, $p = .428$. Due to the very small sample sizes of Year 11 students there results were omitted from the analysis.

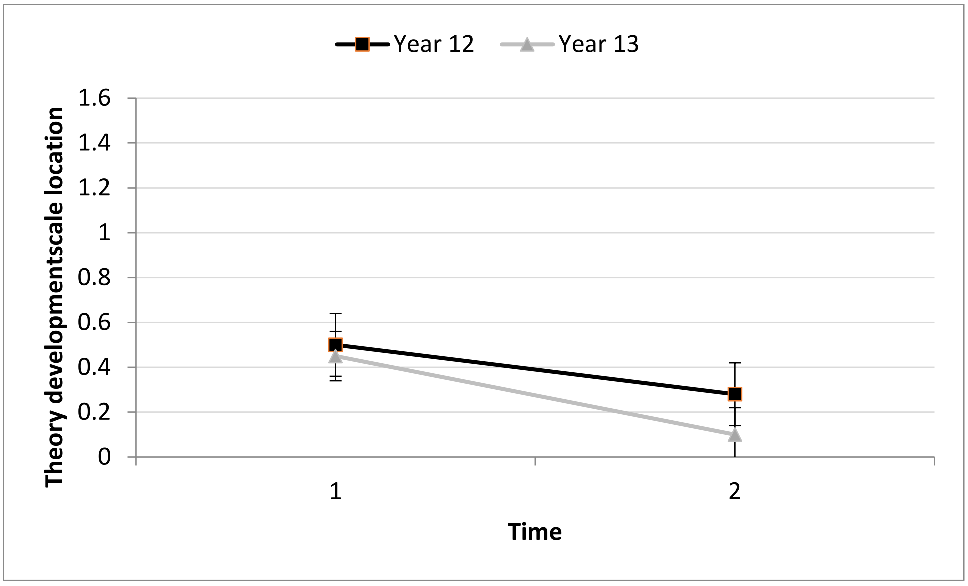


Figure 6.4 Scale location for the theory development variable for Year 12 (n=91) and Year 13 (n=104)students in Term 1 and Term 3

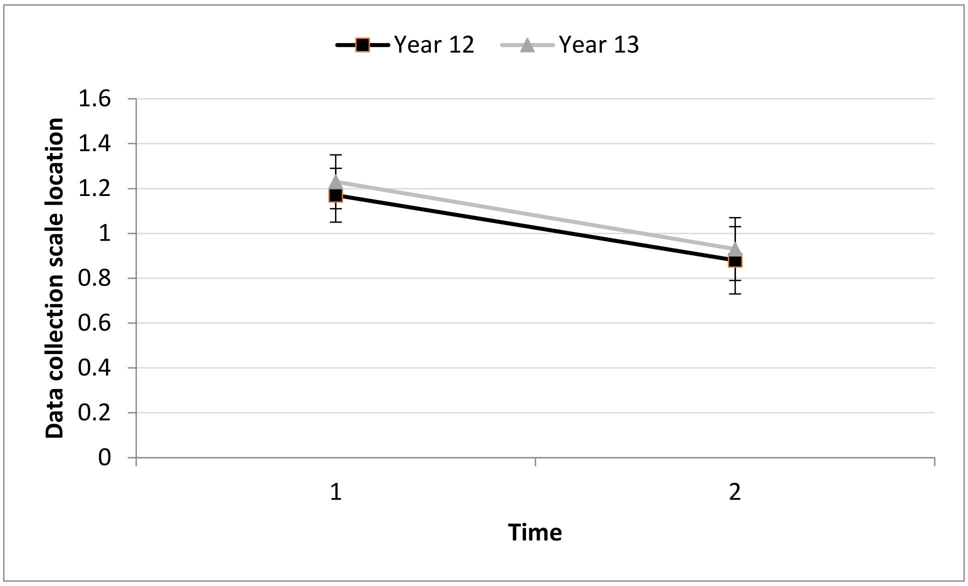


Figure 6.5: Scale location for data collection over time for Year 12 (n=89) and Year 13 (n=103) in Term 1 and Term 3

Therefore, while the data indicate a decrease for both variables over time at Year 12 and 13 over time, these changes were not statistically significant. Similarly, the differences between year levels were not significant. This refutes the hypothesis that Year 13 students would have a more advanced epistemic position or that they would progress at a higher rate.

Discussion: Differences between year levels

The lack of difference between the year levels for both variables refutes the hypothesis that students undertaking science studies in Year 13 will be at and progress at a higher rate. While D. Kuhn (1991) and Mason and Scirica (2006) asserted that epistemological orientation is age dependent and Khishfe (2012b) shown a developmental sequence in the formulation of epistemological view through absolutist to a multiplist to an evaluative position during growing up there is another theory suggesting a forward and backward movement in epistemic development over the years. This is described by Perry Jr (1970) and Yang and Tsai (2010) as fluctuation in epistemic positions until the thinker reaches a mature stand. According to this theory, personal *epistemology* develops with age, but does not follow a linear progression through the years. There is also an interaction between the developments of p*ersonal epistemology,* scientific reasoning and the complexity of the context in which the epistemological position taken. D. Kuhn (1991); Tsai (2004) assert that the practice of argumentation offers opportunities to students to reflect on their epistemological positions and hypothesises that it might contribute to the development of personal epistemology. Their findings furthermore suggested that while students are at the development stage – before reaching the mature stand - can revert to a less advanced position when facing and ambiguous context. The results of the present study implies that the survey consisting items referring to philosophical positions and scientific argumentation could result in conflicting, multiple positions. This then can lead to a withdrawal to an earlier epistemological standpoint (Yang & Tsai, 2010) yielding results showing no significant differences between the different year levels.

Since there were no significant difference between the year levels the results of the two groups can be merged for the further analysis.

Differences between year levels in the different subject areas

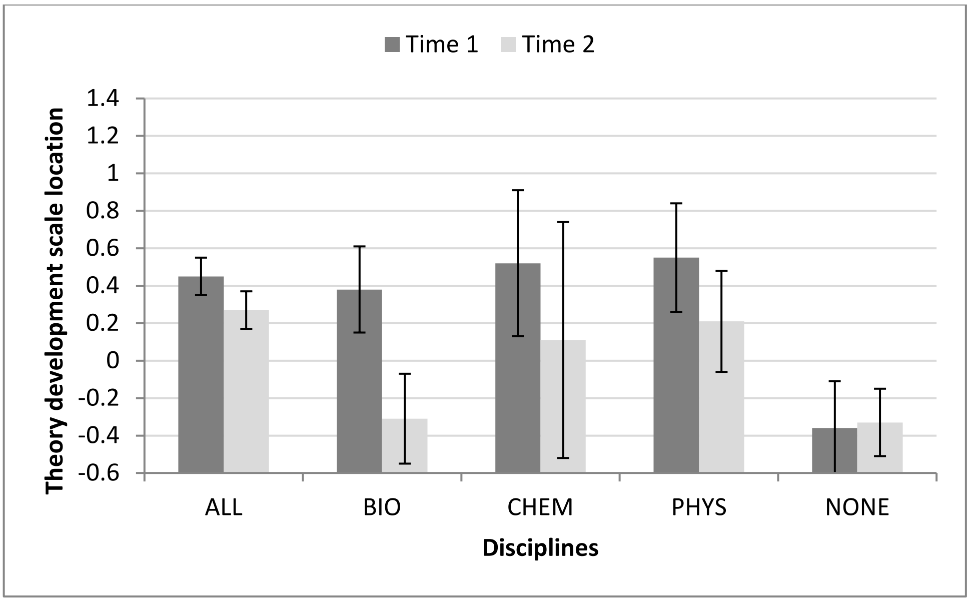
In order to identify whether the same tendency, a lack of difference between the epistemological views of Year 12 and 13 students true at the different disciplines several repeated-measure analysis of variance was conducted as time (term 1 vs. term 3) as the within-subject factor and treatment (science students vs. no science study) as a between-subject factor for each science discipline. In all disciplines at both year levels a significant decline was observed over time in all of the disciplines for both variables but there was no significant combined effect of treatment and year level. Therefore, this analysis did not contribute significantly to the findings of the present study, only confirmed the conclusions of the previous analysis that contrary to the hypothesis there is no significant difference between levels of epistemic views of Year 12 and 13 students.

As this part of the analysis did not yield additional information compared to the previous analysis the details of the analysis is omitted from the report. The complete analysis is shown in Appendix 3.

Differences between studying different science disciplines

Does the study of different science disciplines impact differently upon the development of science epistemology?

To estimate the impact of studying various science disciplines, a series of repeated-measures analyses of variance were undertaken. Each analysis of variance had time (term 1 vs. term 2) as a within-subjects factor, disciplines (two levels: discipline learners and students not studying any science) as a between-subjects factor. Only students completing a course in one discipline were included as a ‘discipline learners’, to differentiate any effects of each discipline. The single-discipline groups created by this procedure resulted in vary small sample sizes; with 30 biology, 6 chemistry, 11 physics and 37 participants not taking science. This reduces both the generalisability of the findings and reduces the likelihood of finding statistically effects. The repeated measures analyses of variance did not indicate any significant interaction between time and any of the disciplines. Therefore, to gain a more accurate insight, several independent samples t-test was conducted comparing the scale location of single discipline learners with students not studying science for the two variables separately. The differences between the scale location of individual discipline learners and students not studying science in term 1 and term 2 for *theory development* and *data collection* variables is shown in Figure 6.6.



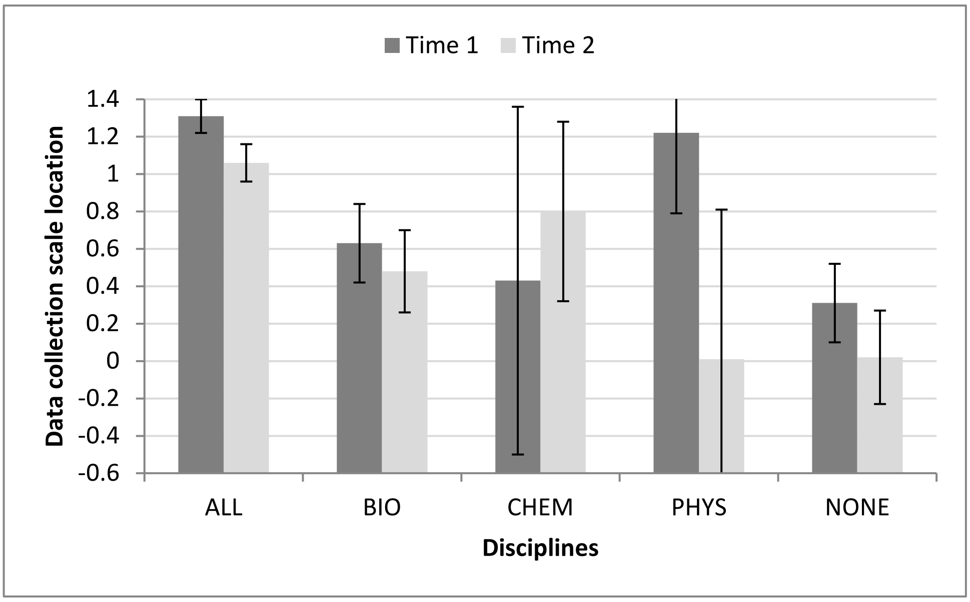


Figure 6.6 Differences between the scale location of individual discipline learners and students not studying science in term 1 and term 23 for theory development (top) and data collection (bottom) variables

The comparison is made between each discipline, shown by the bars labelled as the discipline and students not studying science indicated by the bars labelled 'None' in term 1 and 2. Given the considerably reduced sample sizes the analysis yielded only limited amount of statistically significant results. For the *theory development* variable in biology and physics the learners of these subjects had a significantly higher score compared to the students not learning science at all; term 1 in biology; $t(65) = 2.10$, $p = .04$ and in physics; $t(46) = 1.86$, $p = .03$. While the decline over time was not statistically significant based on the of repeated-measures analyses of variance conducted prior to the t-test, the comparison of term 3 results indicates no significant difference between biology or physics students and students not studying science; term 3 in biology; t (65) = 1.5; p = .93 and physics; t (46) = 1.5, p = .14. In other words by the end of term 3 there was no significant difference between the levels of understanding associated with theory development between students studying biology or physics and those who do not do science. There was no difference between chemistry students and non-science learners in either terms; term, t(41) = 1.87, p = .09; and in term 2 t(41) = .68, p = .53.

For the *data collection* variable a similar tendency was observed in physics. Physics students' had significantly better understanding of *data collection* conceptions at the start of the year, which difference diminished by term 3, term 1; t (47) = 205, p = .046 and term 3; t (47) = - .02, p = .98. There was no statistically significant difference between students taking biology or chemistry and those not studying science in term 1 and 3, biology term 1; t (65) = 1.08, p = .35, term 2; t (65) = 1.32, p = .08 and chemistry term 1; t (42) = .2, p = .84 and term 3; t (42) = 1.78, p = .25.

The analysis was repeated with the combined results of all disciplines for a bigger sample. The difference between the scale location of students studying and not studying science for *theory development* and *data collection* variables is shown in Figure 6.2 and 6.3. The bar labelled 'All' is indicating the combined results of science students and the bar labelled 'None' is showing the scale location of students not studying science in term 1 and 3. The combined results were statistically significant both times for both variables, indicating a significantly higher level of understanding of conceptions associated with science epistemology amongst students studying science compared to those not taking science, *theory development* term 1; t (188) = 3.37, p = .001, term 3; t (188) = 2.75, p = .007, *data collection* term 1; t (187) = 5.01, p < .01, and term 3; t (187) = 4.26, p < .01. These results are confirmed by the results of the first repeated-measures analysis of variance.

Discussion: Differences between studying different science disciplines

The evidence suggest that there was a significant difference in conceptions associated with *theory development* and *data collection* in term 1 between students studying physics and students not learning science. This difference diminished by the second time of measurement in Term 3. Similar tendency was observed in biology, but only for *theory development* variable. This refutes the hypothesis that studying these science disciplines contribute to the development of *theory development* and *data collection* conceptions. While there is significant difference between the scale location between the learners of physics and non-science learners, however causality cannot be confirmed.

As the present study hypotheses an effect of inquiry-type course completion and the development of science epistemology Table 6.6 shows when the inquiry-type work was completed in the participating schools in each disciplines at Years 12 and 13.

Table 6.6 The timing of the completion of inquiry-type unit in the participating schools. Units completed in Term 1 are highlighted grey.

Schools	Level 2			Level 3		
	Biology 2.1	**Chemistry 2.1**	**Physics 2.1**	**Biology 3.1**	**Chemistry 3.1**	**Physics 3.1**
School 1	Term 2	Term 2	Term 1	Term 1	N/A	Term 3
School 2	Term 1	Term 1	Term 1	N/A	Term 2	Term 1
School 3	Term 1	Term 1	Term 1	N/A	N/A	Term 2
School 4	Information not available	Information not available	Information not available	Information not available	Information not available	Information not available
School 5	N/A	N/A	N/A	N/A	N/A	N/A
School 6	N/A	Term 1	Term 1	Term 1	N/A	Term 1
School 7	Term 2	Term 2	N/A	Term 1 and Term 2	Term 2	Term 1
School 8	Term 1	N/A	Term 1	Term 1	N/A	Term 1

The timing of the survey completion could not be fully controlled, contrary to the original plan, the majority of the schools administered the survey towards end of term 1. Table 6.6 shows that most of inquiry-type units were completed in Term 1 in physics and in biology. This suggests that there might be a relationship between the completion of inquiry-type course work and the development of science epistemology conceptions as there was a significant difference between science learners and non-learners scale locations in term 1 while science students were learning about conduction inquiry. However, this difference between science learners and non-science learners diminished by term 3, indicating that these concepts did not reach a stable state or that a single inquiry-type unit without further reinforcement does not have the desired long-term effect. The same tendency was not apparent among chemistry students versus non-science learners and it is evident from the Table 6.6 that the majority of the inquiry-type coursework was carried out in term 2 across the participating schools. This suggests that the development of the concepts associated with *theory development* and *data collection* might be attributed to the completion of science inquiry and should be reinforced during the year. In other words in order to achieve advancement in science epistemology multiple inquiries should be carried out during the year in order to support the development of the epistemic views in science.

The effect of inquiry-type course work on the development of science epistemology

> *Does the completion of internally-assessed, inquiry-type coursework affect the progression of science epistemology and scientific argumentation skills?*

Following on from the previous findings to identify the effect of inquiry-type course work has on the development of science epistemology several two way repeated-measures analyses were conducted. Each analysis of variance had time (term 1 vs. term2) as a within-subjects factor and the completion of inquiry-type coursework – indicated by inquiry-based, internally assessed Achievement Standards assessment tasks in each disciplines - (two levels, completion and non-completion) as the between-subject factors and the combined effect of time and year level was also analysed.

The changes in *theory development* scale location over time for those completed inquiry-type course work compared with those who did not in each of Year 12 and 13 are shown in Figure 6.7 separately for each science discipline.

There were 40 iology, 43 chemistry, 28 physics students in the Year 12 and 19 biology and 11 physics in Year 13 samples. There were no Year 13 chemistry students completing inquiry.

Most importantly, the completion of Year 12 chemistry inquiry-type coursework had a significant effect on the progression of *theory development* conceptions only in chemistry, with a more advanced epistemological understanding evident amongst students completing inquiry-type course work; $F(1, 235) = 14.83$, p , .001. The change over time and the interaction between inquiry and time was not significant statistically; no main effect of time; $F (1, 235) = 2.75$, $p = .09$, and no interaction between time and inquiry course completion; $F < 1$. In biology and physics the decline in scale location over time was statistically significant; in biology, $F(1, 235) = 5.15$, $p = .03$ and in physics, $F(1, 235) = 4.59$, $p = .03$. There was no effect of inquiry-type course work; in biology, $F(1,235) = 2.9$, $p = .09$ and in physics; $F < 1$. There was no interaction between time and inquiry-type course completion in biology, $F < 1$; or physics, $F < 1$. There were no significant changes over time, nor significant differences between students doing inquiry and the ones who do not for Year 13 groups in either discipline. In biology there was no significant main effect of inquiry; $F < 1$; no significant main effect of time; $F (1, 235) = 2.63$, $p = .11$; and no interaction between time and inquiry; $F < 1$. In physics there was no significant main effect of inquiry; $F < 1$, no significant main effect of time; $F < 1$, and no interaction between time and inquiry; $F < 1$, $p = .82$. In chemistry there were not any students completing inquiry.

It is also apparent that some of the sample sizes were very small, suggesting that a repeated study involving more participants could yield more reliable data and obtain more detailed information on the relationship between inquiry-type coursework and the development of science epistemology. The results also indicate that students not completing inquiry-type course work had very similar scores to the scores of students doing science inquiry by term 3.

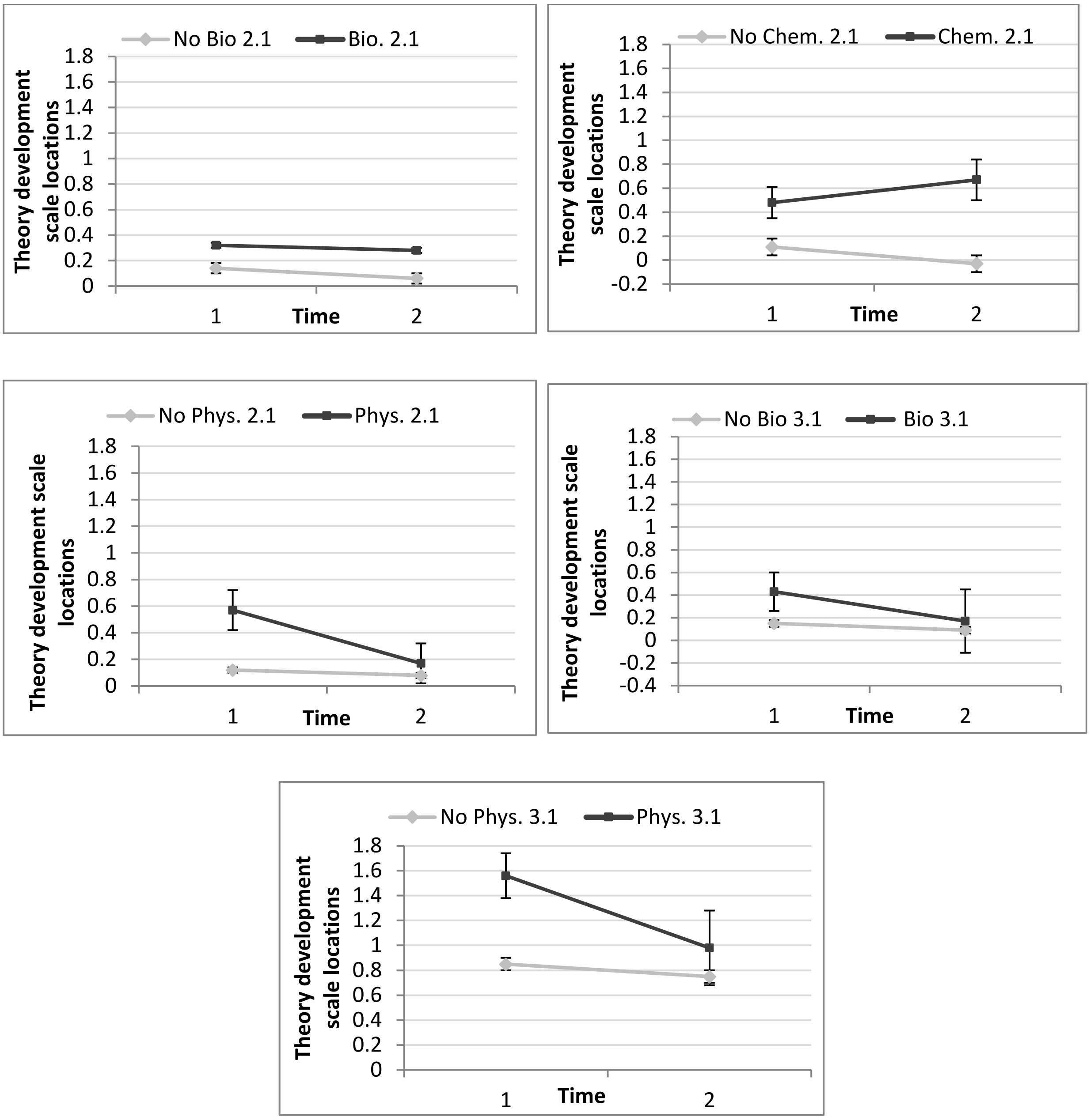


Figure 6.7 Scale locations for the theory development variable in Term 1 and Term 3 for students completing inquiry-type course work and those who do not in different science disciplines.

The changes of *data collection* scale location over time for those completing inquiry-type course work and for those who do not in different science disciplines at Year 12 and 13 is shown if Figure 6.8. The sample sizes were the same as for *theory development*.

Similar tendencies were observed for the *data collection* and *theory development* variables. Only Year 12 chemistry students had significantly higher scores compared with students not completing inquiry-type course work; $F(1, 233) = 6.28$, $p = .01$, but no significant main effect of inquiry was evident for any other courses; in biology, $F < 1$, and in physics; $F < 1$. In all Year 12 courses there was a main effect of time, meaning that all Year 12 students' scores decreased over the three terms of study significantly; biology, $F (1, 233) = 5.52$, $p = .02$; in chemistry; $F (1, 233) = 10, 44$, $p < .01$; and physics; $F (1, 233) = 9.31$, $p < .01$. There was no significant interaction between time and inquiry in either biology; $F < 1$; nor in chemistry; $F (233, 1) = 2.47$; or in physics; $F (1, 233) = 2.39$, $p = .13$. At Year 13 level there was no significant difference observed in any of the disciplines; in biology there was no significant effect of time; F((1, 233) = 105, $p = .30$, no significant combined effect of inquiry and time; $F < 1$. In chemistry there were no inquiry participants so the analysis could not be conducted.and in physics there was no significant effect of time; $F(1, 233) = 3.42$, $p = .07$, no significant interaction between time and inquiry; $F < 1$, $p = .48$ and no significant effect of inquiry; $F (1, 233) = 1.27$, $p = .26$. Again, while the effect of inquiry-type course work over time was not statistically significant, given the small sample sizes further studies potentially could provide statistically significant data. In order to test the hypothesis that inquiry-type work actually contributes to epistemic development another analysis was conducted, in which all disciplines' results were analysed together in order to gain data from a bigger sample. The changes of *theory development* and *data collection* scale location over time for those completing inquiry-type course work and for those who do not in all of the science disciplines at Year 12 and 13 is shown in Figure 6.9.

There were 63 students in the inquiry sample and 172 in the no inquiry sample in the Year 12 group. At Year 13 level there were 26 participants in the inquiry sample and 209 in the no inquiry sample. For both variables – *theory development* and *data collection* – in the Year 12 groups a decrease over time was observed. For *theory development* significant main effect of time; $F (1, 235) = 4.88$, $p = .02$, significant main effect of inquiry; $F (1, 235) = 8.49$, $p < .01$and there was no significant interaction between time and inquiry; $F < 1$. For *data collection* at Year 12 there was a significant main effect of time; $F(1, 233) = 7.74$, $p < .01$, no significant interaction between time and inquiry; $F < 1$, $p = .62$ and significant main effect of inquiry; $F (1, 233) = .042$. .At Year 13 level there was no statistically significant change for either variable. For *theory development* there was no significant effect of time; $F (1, 235) = 3.04$, $p = .08$, no significant interaction between time and inquiry, $F < 1$, and no significant main effect of inquiry; $F < 1$, $p = .67$. For *data collection* there was no significant main effect of time; $F (1, 233) = 2.92$, $p = .09$, no significant interaction between time and inquiry; $F < 1$, and no significant main effect of inquiry; $F (1, 233) = 2.63$, $p = .11$.

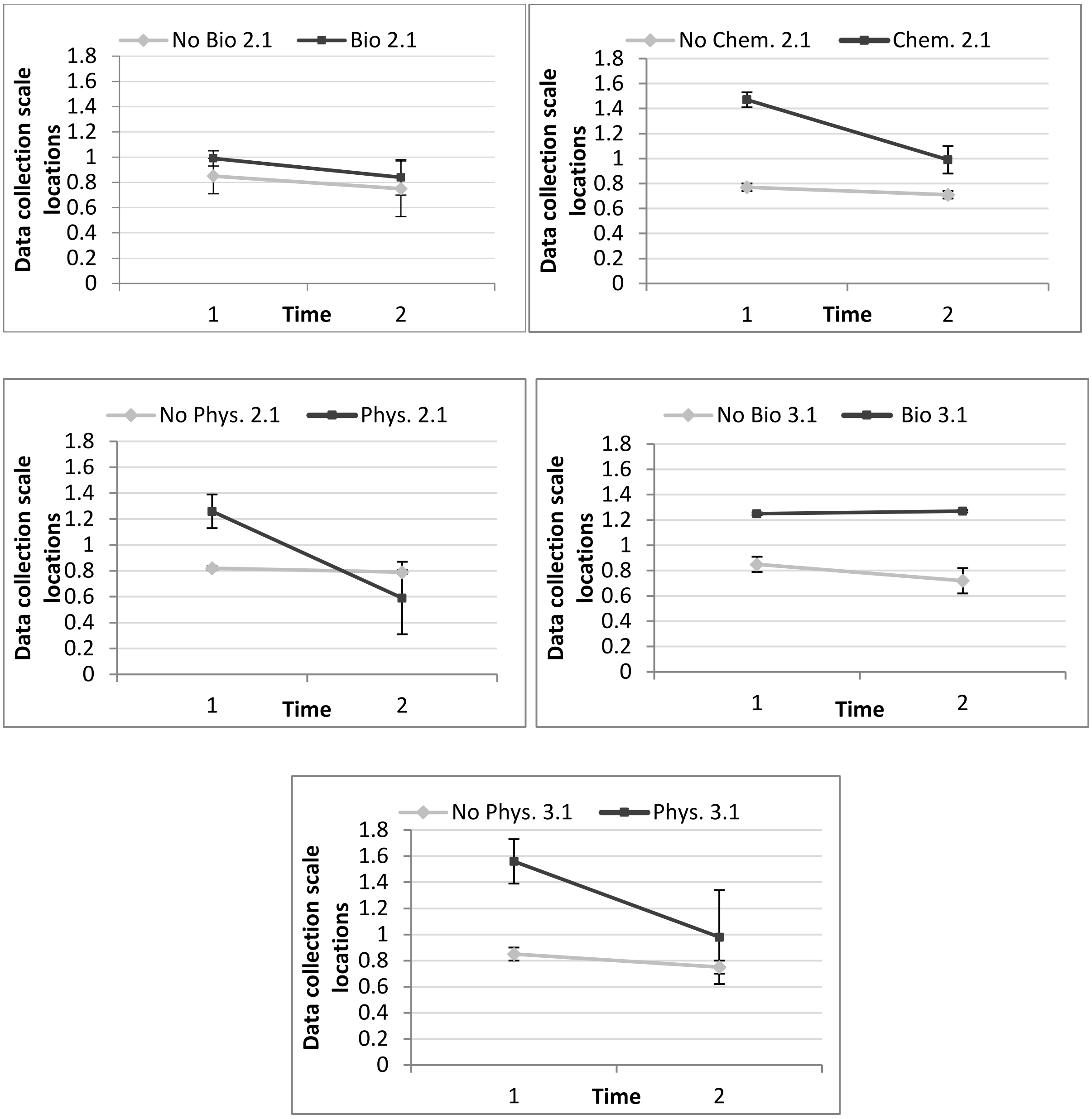


Figure 6.8 Scale location for the data collection variable in Term 1 and Term 3 for students completing inquiry-type course work and those who do not in different science disciplines.

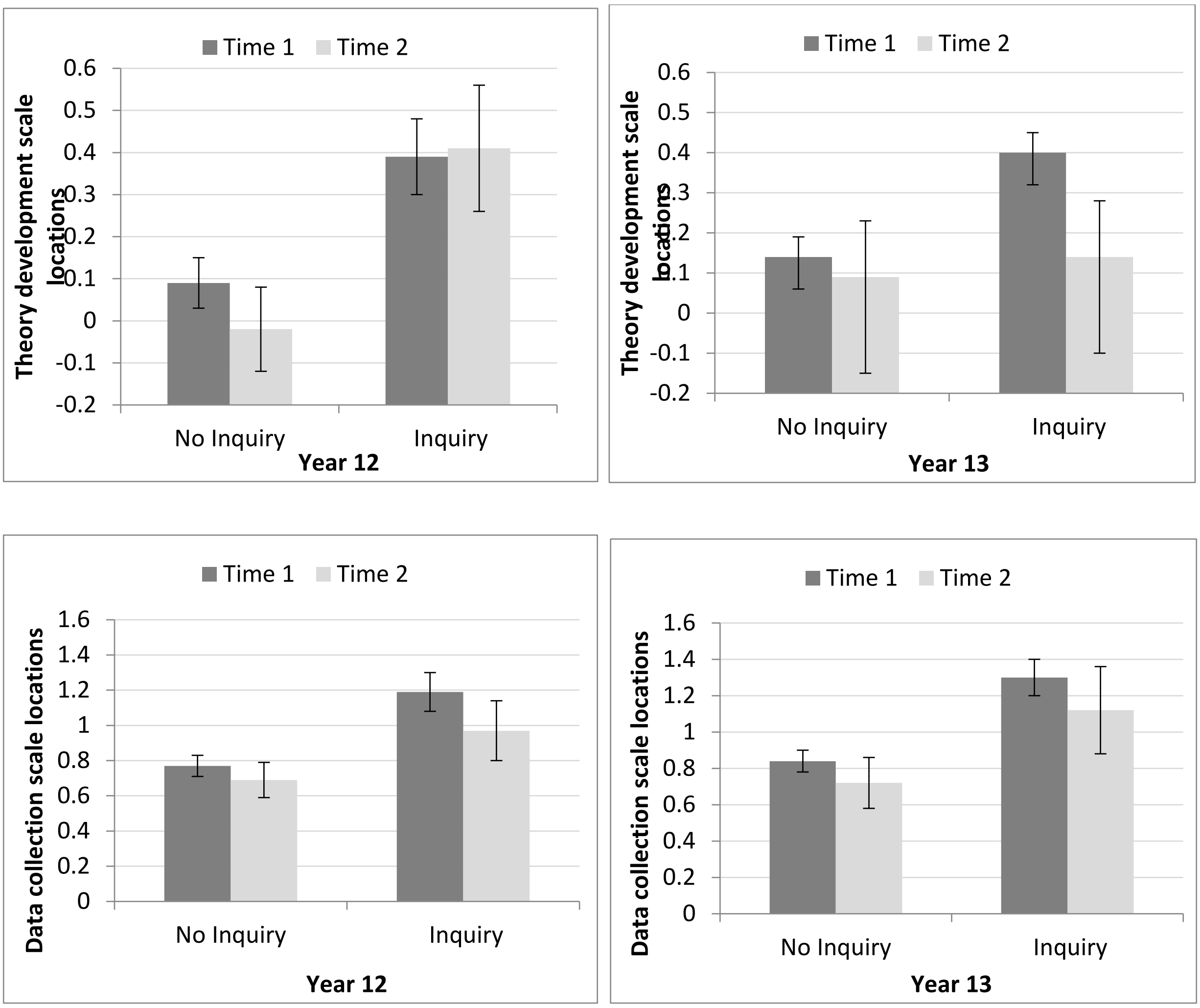


Figure 6.9 Theory development (top) and data collection (bottom) scale locations for those completing inquiry-type course work and for those who do not in all of the science disciplines at Year 12 and 13 in Term 1 and Term 3.

Discussion: The effect of inquiry-type course work on the development of science epistemology

The most important finding from this analysis is that there was a significant decline over time amongst Year 12 students in scale location for both variables for most disciplines, whereas at Year 13 no significant changes were observed. The data does not provide statistically significant evidence for an interaction between time and inquiry at either level, in any science disciplines. This finding therefore does not support the secondary hypothesis that the completion of science inquiry units early on the year followed by lack of exposure to these concepts contributes significantly to the decline of conceptions associated with science epistemology. The combined results from all disciplines indicate, however, that at Year 12 those students who complete inquiry type course work have significantly more advanced epistemic view, compared to students not doing inquiry. The difference between students completing inquiry and ones who do not diminishes at Year 13. These findings suggest that the completion of inquiry-type coursework at Year 12 supports the development of science epistemology. The understanding acquired at Year 12 then seemingly becomes a more stable epistemic view, and less receptive to changes the following year. Given the relatively small sample sizes for each inquiry type-course in individual disciplines at the two levels, and taking into account the other evidence arising from the present research, there might be a connection between the decline over the three terms amongst students completing inquiry-type course work at the start of the year and the fact that they do not do repeated inquiries. However, to establish the connection robustly, further studies will need to be conducted.

The correlation between students' NCEA results and students' epistemic views

To what extent do students' NCEA results correlate with students' epistemic views and scientific argumentation skills?

To conduct this analysis students' results for the internally assessed results were used, for two reasons. First, the externally assessed examination results were not available and second, there was a greater variation between schools' internally assessed assessment choices. Because the sample size for each disciplines' assessment results were very small, two new categories was created, one of them containing Year 12 students' and the other one the Year 13 students' best inquiry results.

A Pearson's correlation analysis was run to investigate the relationship between the 102 Year 12 highest inquiry results and theory development scale locations in term 1 and 3. There was a weak positive correlation between the assessment results and the first round's theory development scale location ($r = .23$, $N = 103$, $p = .02$) and also a weak positive correlation between the assessment results and the second round's theory development scale location ($r = .25$, $N = 103$, $p = .01$). A similar analysis showed no significant correlation between inquiry assessment results and theory development scale locations in either rounds at Year 13 (round 1; $r = .05$, $N = 126$, $p = .57$ and round 2; $r = .05$, $N = 126$, $p = .56$). This confirms the hypothesis for the Year 12 students that predicated some correlation between NCEA results and epistemic view; however the hypothesis is refuted for the Year 13 students.

Another Pearson's correlation analysis was carried out to determine the relationship between 102 Year 12 NCEA inquiry assessment results and the *data collection* scale location. There was a weak positive correlation in both rounds ($r = .38$, $N = 102$, $p <.01$ in the first round and $r = .28$, $N = 102$, $p < .01$ in the second). At Year 13 there was no significant relationship between the NCEA assessment results and the *data collection* scale location both times ($r = .17$, $N = 125$, $p = .06$ in the first round and $r = .17$, $N = 125$, $p = .07$ in the second). The results again confirm the hypothesis that some correlation would be found between the NCEA inquiry-type assessment results and epistemic view at Year 12, however the hypothesis is refuted at Year 13 level.

This analysis suggest again a decline of conceptions associated with data collection at Year 12 level, as the correlation between the grade and the survey results were weaker at the second time point. This means that the NCEA results gained early on in the year less predicting an informed epistemic year towards the end of the year.

Change in means for individual questions for the two variables

The initial one-way analysis does not provide insight into how individual items contributed to these overall results. The next analysis compared the percentages of correct responses for each item. Figure 6.10 and 6.11 shows the results.

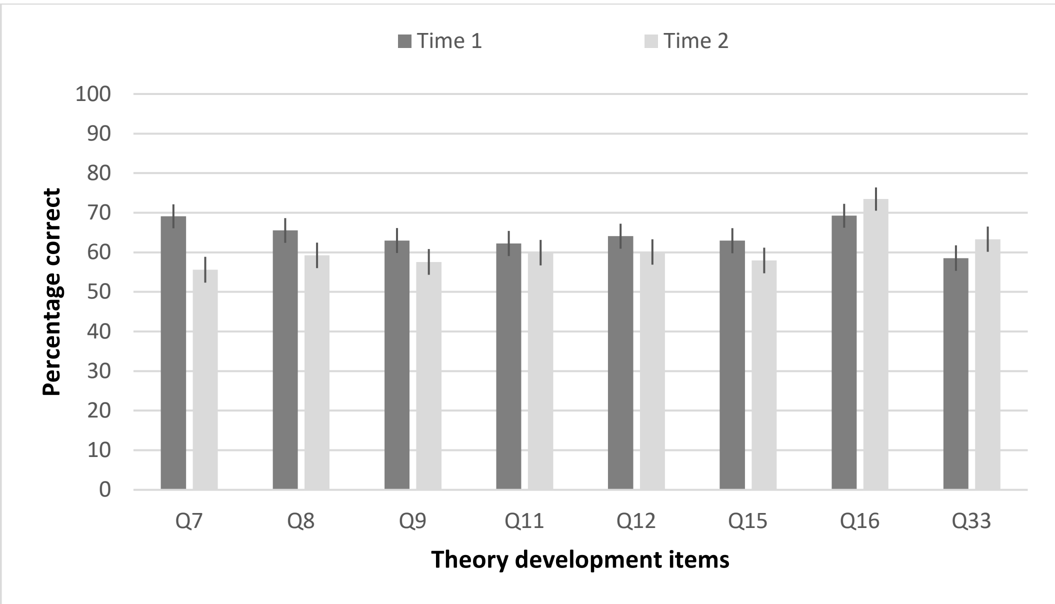


Figure 6.10 Change in percentages correct between Time 1 and Time 3 for the theory development items

Taking error bars into consideration - that is an indicative of the confidence in the extent to which the mean represents the true value – students showed significant progression in the following items. Scores decreased for most items decreased, significantly in the case of items 7, 8 and 9 and insignificantly for items 11, 12and 15. An insignificant increase of percentage correct was observed in items 16 and 33.

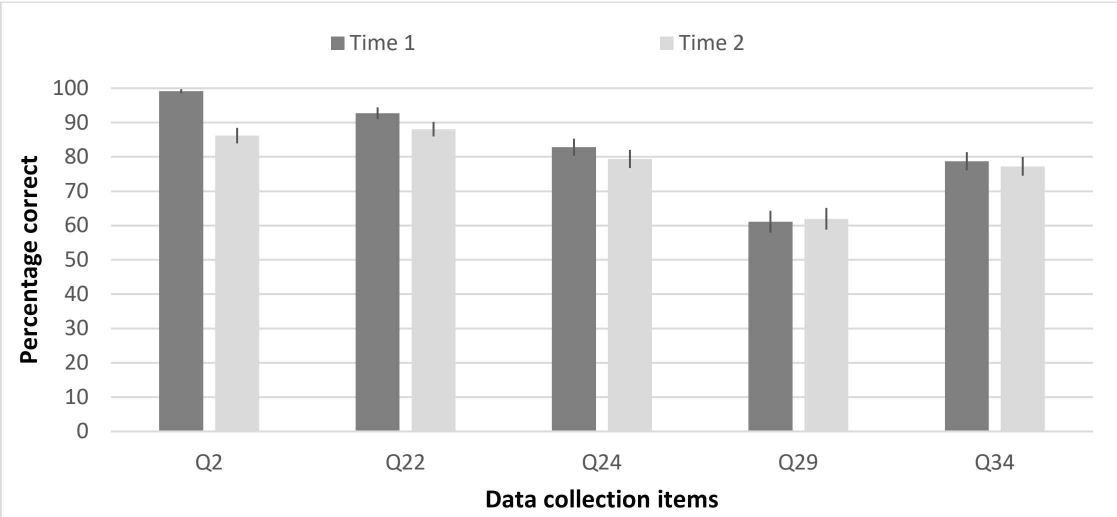


Figure 6.11 Change in percentages correct between Time 1 and Time 2 for the data collection items

From the data collection items there was a decrease in the percentage correct, items 2 and 22 a significant decrease, whereas in the case of items 24 and 34 the decline was insignificant. An improvement in the score was only observed in item 29, but this increase was insubstantial.

A summary of changes in percentage correct is shown in Table 6.7.

Most significant negative progressions were observed in items 7, “Scientific knowledge is solely established by experiments “and 2, “Scientific theories can change given new evidence or interpretations of data“.

Less but still significant negative progression was observed in items 8, “If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change”; 9, ”Scientific method always follows the same steps in the same order”

Table 6.7 Significant and non-significant changes of percentage correct of individual items

	Insignificant change in percentage correct	Significant decrease in percentage correct
Theory development items	11. If sufficient data were available there would be no controversy over scientific theories.	7. Scientific knowledge is solely established by experiments.
	12. Scientists know that they have the right answer to a research question if they have followed the scientific method.	8. If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change.
	15. Scientific theories are fact-based and not influenced by scientists' opinions.	9. Scientific method always follows the same steps in the same order.
	16. When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data.	
	33. Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus' remains.	
Data collection items	24. The validity of these experiments cannot be decided because there is no information about how other variables were controlled.	2. Scientific theories can change given new evidence or interpretations of data.
	29. We can be more confident in Group B's result because the range between the largest and the smallest measurement is less.	22. The reliability of the data could be improved by repeated measurements in both groups' investigation.
	34. The individual pieces of evidence one-by-one are not very relevant; rather the accumulation of these pieces of evidence gives more reliability to the claim	

Positive progression was observed in items 16, "When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data" and 33, "Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus' remains".

Significant change among data collection items was a negative progression in item 2, "Scientific theories can change given new evidence or interpretations of data" and 22, "The reliability of the data could be improved by repeated measurements in both groups' investigation". The former item was in of the *Nature of science* section and loaded on the data collection factor. In the first round (Time 1) there was 99% correct response, which then at the second round (Time 2) decreased to 86 %. So, while there was a significant decrease in the percentage of correct answers, after the decrease students still had the second highest score on this item at the second measurement time compared to all the studied items. Item 22 also had a high score of 93%, which decreased from 93% to 88% between the two times of measurement.

The most significant change, a negative progression was observed in item 7, “Scientific knowledge is solely established by experiments “changing from 69 % to 56 % between the two points of measurement of the theory development items. Less, but still significant change of percentages corrects were observed on items from the theory development variable in items 8, “If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change“, 9, “Scientific method always follows the same steps in the same order “with a decrease from 66% to 59% and 63% to 58% respectively.

While the error bars indicate less confidence in the extent to which the difference between scores between the two measurements are likely to be the result of actual progression rather than attributed to measurement errors the increase in percentage correct in items 16, “When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data“ and 33,“Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus’ remains” is noteworthy as these students’ scores improved most significantly in these items. The increase between the two times of measurement 69% to 73% and 59% to 63% respectively.

Although the scores decreased for most items over time, there is possibly different reason for the similar tendencies. Items associated with the philosophical underpinnings of the development of scientific knowledge - or *nature of science* conceptions - are developed successfully when addressed by explicit instruction (F. Abd-El-Khalick et al., 2004; Khishfe, 2012a; McDonald, 2010). This is not yet a well-established practice in New Zealand schools, it is especially an abended area of teaching programmes at senior levels. Hipkins (2012) stipulates that at NCEA levels 1-3 the combined effect of high-stake assessments and the lack of specific achievement objectives addressing *nature of science* ideas lead to a negligence of this important aspect of science. Furthermore she points out other impending factors, such as at times teachers’ lack of understanding of *nature of science* conceptions and the absence of resources. Another plausible contributing factor is the ambiguity of the *nature of science* statements. For instance the highest rate of decrease of scores was observed on item 7. “Scientific knowledge is solely established by experiments”. The ambiguity arises from that while inferences, imagination and creativity is important in the development of science knowledge, scientific evidence, however, is essentially and most frequently based on data sought from experimentation. Similarly ambiguous statement is item 8." If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change". While philosophically scientific knowledge only holds up until it is disproven, therefore absolute truth cannot be established, at the same time as Reneé S Schwartz and Lederman (2008) points out "the knowledge is tentative, yes, yet nonetheless durable because […] it is accepted within the community based on consistency and strength of argument" (p. 729). Meaning that while absolute truth cannot be established – according to realist and post-positivist perspectives -, however some well-established scientific concepts, theories and models widely accepted and retain their truth value over time. We can then ask: to what extent do we expect students to distinguish between the durability of scientific knowledge and the existence (or lack of) absolute truth.

Decline in the data collection variable could be attributed to the fact that in most participating schools students completed the science investigation courses early in the year shown in Table 6.6. During these courses they learn about the collection, processing data, drawing conclusions and evaluating the investigation. As the administration of the survey could not been fully controlled in most schools the surveys were completed towards the end of Term 1, therefore the concepts associated with data collection were fresh in students' minds. Then again, providing only one opportunity to form an understanding can compromise the rate of retention, which could be reflected in the decline of the data collection scores.

CHAPTER 7

Discussion

The aim of the present study was to examine the influence of studying science on the development of science epistemology in senior secondary years. The value of epistemic development has been argued from various positions including *liberal education*, *scientific literacy* and *powerful knowledge* discourses. In each of these discourses great emphasis is placed on the role of epistemic development as a process of gaining an understanding of the power and limitations of scientific knowledge. This understanding in turn enables students to distinguish between knowledge based on robust evidence and weak knowledge claims. People are then empowered to make informed decisions based on their own critical reasoning, rather than on claims justified solely on the basis of authority. In other words, scientific epistemology enables people to establish their own intellectual authority.

The two hypothetical dependent variables in the present study, *nature of science* and *scientific argumentation*, did not form well-defined constructs; the questionnaire items putatively comprising each of these did not correlate highly with one other. This was evident from the EFA; the two extracted factors, which were almost uncorrelated, each included items from both sections. The two construct suggested by the EFA are related to *theory development* and *data collection*. The former relates to the mental processes that link empirical data to theory, as well as to some assumptions about these processes. The latter comprises conceptions about the experimental conditions that are requisite for valid and reliable investigations that, in turn, yield evidence that can be used to support or refute hypotheses.

One of the most important findings emerging from the data was that students participating in science courses have a more advanced epistemic view of science than those who have not studied science. A comparison of science students' and non-science learners' scale locations indicated greater understanding of both *data collection* and *theory development* for those studying science than those not studying science. However, contrary to the hypothesis, science students did not advance at a higher rate during the participation of science course; instead students' scores declined on the *data collection* variable and showed no significant change on the *theory development* variable. Thus higher overall understanding evident for the science learners compared with the non-learners could be a result of different dispositions toward science, meaning that students with a better understanding of science epistemology might be more likely to choose science subjects than those with less advanced understanding once science becomes non-compulsory (usually Year 12 and 13). In other words, the present quasi-experimental inquiry involved pre-existing groups – science learners and non-science learners – which were self-selected possibly with different *priori* levels of scientific-epistemological sophistication, thus resulting in sample bias.

The extent to which studying science contributes to the development of science epistemology is not clear from the present study. For the *theory development* variable the scale location for science learners remained static, whereas for *data collection* variable a decline was observed between Terms 1 and 3. This evidence refutes the hypothesis that the completion of science course supports the development of science epistemology. A plausible explanation for the decline in the *data collection* scale location is that students learned the concepts associated with this variable during inquiry-type units, which in most participating schools in most disciplines are run near at the start of the year - around the time of the first sampling – which is likely to have contributed to a more advanced understanding at the time. The decline in the level of understanding during the following two terms could be therefore attributed to a lack of reinforcement of these conceptions.

Another plausible explanation for the decline in science students' understanding of *data collection* is that, according to a body of literature, both *nature of science* (F. Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick et al., 1998; Eastwood et al., 2012; Khishfe, 2012a, 2012b; Lederman, 2007; McDonald, 2010; Reneé S. Schwartz et al., 2004) and *scientific argumentation* instruction (Driver et al., 2000; R Gott & Duggan, 2007; R Gott & Johnson, 1996; Richard Gott & Roberts, 2008; Roth, 2004; Jim Ryder, 2001, 2002; Salter & Atkins, 2013; Sandoval, 2003, 2005; Sandoval & Millwood, 2007) concepts are only effective in building epistemic understanding if they are addressed explicitly in pedagogy. To some extent explicit instruction in relation to these concepts occur in New Zealand schools during inquiry-type course work, when students learn about the principles of scientific investigations. However, it appears that, in most cases, concepts of nature of science are not addressed effectively (Hipkins, 2012; Hipkins & Barker, 2005). There are multiple reasons for this, for example teachers' lack of understanding of the tenets and a lack of resources.

A second aim of the present inquiry was to identify differences between Year 12 and 13 students' epistemic views. The data did not support the hypothesis that Year 13 students would have more advanced epistemological views compared with the Year 12 group. Although some research suggest that epistemological orientation is age dependent (D. Kuhn, 1991; Mason & Scirica, 2006) other research indicates a forward and backward movement in epistemic development over the years. The notion instable is furthermore supported by Perry Jr (1970) and Yang and Tsai (2010) who noted that epistemic understanding is a fluctuation in epistemic understanding until it a stable state is reached, after periodies regressions to earlier, less advanced positions. Khun's (1991) and Tsai's (2004) findings indicate that scientific argumentation supports the development of a stable position by allowing students to reflect on their own knowledge generative processes. On the other hand, Yang & Tsai's (2010) results suggest that ambiguous contexts can trigger a reversion to an earlier epistemic position. The theories about epistemic development therefore imply that an emphasis on the development of *scientific argumentation* at the expense of (the ambiguous) *nature of science* concept would provide more effective support for the development of a more advanced and stable epistemic view.

The findings of the third analysis, into differences between students of the various disciplines of science, confirmed the hypothesis that there would be no significant differences between those completing biology, chemistry or physics courses. For example physics students performed better on both of the variables compared with non-science learners and for *theory development* biology students also had significantly higher scores. The extent to which actual participation in science courses contributed to this difference – as opposed to it being a result of sample bias – was inconclusive because the first analysis of variance did not indicate any significant main effect of time or interaction between time and discipline. The lack of significant results could be attributed to the relatively small sample sizes of students studying single disciplines.

Further findings of the present study provide more evidence for an existing relationship between progression in epistemic understanding and conducting science inquiries. Although the evidence does not fully establish the effect of science inquiry on understanding of the *theory development* and *data collection* concepts, students who complete inquiry-type coursework had significantly higher scale locations than students who did not. While the effect of science inquiry could not be fully established – probably due to small sample sizes – the hypothesis was supported by a weak correlation between inquiry grades and scores on the survey.

The hypothesis that, when inquiry-type coursework takes place early in the year, understanding of key epistemological concepts would decline due to a lack of reinforcement is further supported by the decline of scale locations for Year 12 students who had completed an inquiry standard, and by a decreasing correlation between inquiry-type assessment results and survey scores over time. While this hypothesis was not fully confirmed, the evidence suggests a relationship between inquiry-type coursework and the development of science epistemology. This requires further investigation with more adequate sample sizes.

Analysis of the theoretical frameworks concerned with epistemological development could provide an alternative explanation for the declining trends over the three-term-duration of the study: The three main theoretical frameworks in science education are *personal epistemology*, *nature of science* and *scientific argumentation*. Personal epistemology relates to progression through epistemic stages – represented by stages similar to various philosophical positions, such as absolutist, relativist and so on – and the ways in which learning is affected by epistemic development. *Nature of science* is often equated with science epistemology, but its content is debated and it includes a set of tenets describing links between scientific knowledge, philosophical positions and social practices. The present study has shown that it would be more accurate to say that *nature of science* is reflective of the *social practices of science* and the *nature of scientific knowledge*, rather than science epistemology. *Scientific argumentation*, on the other hand, is the essence of the *science process*, and cannot, therefore, be divorced from science epistemology; understanding of how science knowledge is advanced, and the limitations and power of scientific knowledge only can be comprehended if the process that scientific progress is understood. An understanding of the principles of *scientific argumentation* enables people to support or refute a hypothesis by considering robust evidence. Moreover, it helps them to ‘look back’ on how a knowledge claim has been argued, evaluate the strength of evidence on which the claims are founded, and independently assess the validity and reliability of evidence taken to support claims. For these reasons learning the principles of *scientific argumentation* appears to be essential in the development of intellectual authority.

The present EFA therefore provided quantitative evidence that some aspects of *nature of science* are associated with *scientific argumentation* conceptions. A particularly important aspect of this finding was that *nature of science* conceptions develop in relation to concepts associated with science inquiry. One of the most questionable aspect of the *nature of science* construct is represented in the literature (Lederman, 2006; 2007, McComas et al. 2002) the way in which its parameters of *nature of science* are asserted to be distinct from the science inquiry process.

While the absence of science inquiry from the concept of *nature of science* appears to be the status quo as far as education research goes, this apparent consensus might be the result of circular reasoning. For example, some researchers (e.g. Wong & Hodson, 2009) confirmed the tenets of nature of science by using a survey based on the existing tenets. This, exclusion of the processes associated with science inquiry, contradicts the opinions of scientists: they emphasise learning about the methods, or process of science to support the development of an understanding of science-knowledge generative processes, rather than focusing on the philosophical underpinnings, or the social aspect of science.

A relationship between science inquiry and *nature of science* tenets is apparent in a study conducted by Reneé S Schwartz and Lederman (2008) to elicit scientists' views on the *nature of science* tenets from various disciplines. Here the most commonly-used open-ended instrument designed to measure *nature of science* conceptions, *Views of Nature of Science*, was used - which is based on the generally accepted tenets. Schwartz and Lederman strictly distanced *nature of science* from science inquiry by defining the subject of their study as *nature of scientific knowledge*[1], however what really stands out is that all of the participating scientists conceptualised the tenets in relation their own inquiry processes. The responses to each question were based on their own experiences, practices and logic inherent in scientific inquiry. While Schwartz and Lederman identified the commonalities and differences between these scientists' views on the *nature of science* tenets in relation to the field of studies, what they failed to recognise was that each tenet, in the absence of the actual process that underpins it, is meaningless.

It is very likely that science students conceptualise statements referring to *nature of science* concepts in a similar way to practising scientists; that is, in relation to their own inquiry experiences. Consequently, it might be expected that some nature-of-science concepts would develop in relation to inquiry experiences, as a consequence of understanding these processes. The interwoven character of *nature of science* conceptions and the inquiry process was confirmed by the results of the present EFA, which indicated a correlation between the development of knowledge relating to *scientific argumentation* and to *nature of science*.

The separation of *nature of science* from science inquiry leads to several flaws in the conceptualisations of *nature of science*, which inevitably affect the results of surveys used to investigate the development of *nature of science* conceptions. This is possibly the best

[1]A term Lederman (2006) introduced as a response to criticism for divorcing *nature of science* from science inquiry. In his reasoning Lederman states that scientific inquiry involves various science processes in a cyclical manner, whilst nature of science is the epistemological underpinnings of these processes and that of the resulting knowledge.

explanation for the finding that students' understanding of concepts associated with *theory development* and *data collection* declined during three terms of studying science. To illustrate, one of the fundamental flaws in the basic assumptions informing the *nature of science* tenets is that, the tentative nature of science is often equated with a relativist position by researchers in educational fields – and this is perceived as the most advanced position -, whereas, tentativeness often accompanies a realist view amongst scientists themselves. This insight is supported by an earlier study conducted by Glasson and Bentley (2000) which appeared to show multiple positions being held by scientists, relativist and realist (or post-positivist) depending on the audience they explained their findings to. Schwartz and Lederman's (2008) study sheds light on this seeming contradiction: Scientists affirmed that scientific knowledge is tentative, however some suggested "that science attains certain knowledge (that is, knowledge of reality separate from the observer) or that science progresses nearer and nearer to certain knowledge" (p. 742). This idea of a progression towards a better approximation of the truth is captured by one of the responses of Schwartz and Lederman's (2008) study:

> "All scientific knowledge is subject to question, doubt and criticism (a further distinction from religion) … Nonetheless, someone will eventually challenge an accepted scientific finding and take a fresh look at it. … That is the self-corrective nature of science. Does science lead to universal truths? It leads to close approximations of universal truths." (p. 742).

Based on these statements, scientists would be regarded taking up post-positivist (or absolutist) epistemic position, which according to the *nature of science* literature is regarded as a *naïve* epistemological view

This flaw in the interpretation of the tentative nature of science knowledge in relation to the philosophical position underlying it has possibly contributed to the declining trends observed in the present study. For example, students scored significantly lower on some items in relation to tentativeness in Term 3 compared with Term 1. Two examples of this were for the following items "If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change" and "Scientific theories can change given new evidence or interpretations of data". According to informed *nature of science* views the first statement is false – or reflective of a naïve epistemic position. However, according to some scientists' views the aim of scientific practice is to attain certain knowledge and to progresses toward the best approximation of absolute truth. Similarly, with regard to the second statement, scientists agree that scientific theories can change in the light of new findings or new interpretations. Then again they also agree that there are some theories, which give such close approximation to observed phenomena that then become a widely accepted "truth". This position is reflected in one of the scientist's statement in Schwartz and Lederman study: "The truth will be revealed with enough data" (p. 749). Therefore, while students might have progressed towards a view more resembling the views of scientists, as a consequence of the flaws in the *nature of science* construct, they scored lower at the second time of measurement. Schwartz and Lederman also assert that the engagement in scientific inquiry as a successful member of the science community does not necessarily ensure informed *nature of science* conceptions; "those who engage in authentic scientific inquiry may or may not develop NOS [nature of science] views aligned with positions for scientific literacy" (p. 764). This, in turn, raises questions regarding the exact purpose of *nature of science* if it is not reflective of the positions of those actually practising knowledge generative processes.

While the actual role of science inquiry in the development of science epistemology remains conjectural, it is important to note a relative lack of emphasis on inquiry-type coursework participation in the sample: There were 89 students who completed inquiry-type coursework across the two cohorts, out of a total of 200 science students. Furthermore, Table 6.6 shows that, at one school, there was no science inquiry during Year 12 or 13 and that no schools offered Chemistry inquiry units at Year 13 level. This, coupled with the common practice of delivering at most one inquiry unit in each science course could potentially critically compromise epistemic development.

Sheehan (2013) conducted a similar study exploring the development of historical thinking as the result of internally-assessed, research type course work. He noted that internally-assessed work appears to be less rigorous academically in the public eye, and external examinations viewed as a more valid measure of intellectual development. Nonetheless, he found that internally-assessed coursework supports the development of historical thinking, as students are required to use methods, skills and ways of thinking similar to that of historians. The similar impact of internally-assessed coursework in history and science is unlikely to be a coincidence.

Learning about the steps, conventions, practices and language of a discipline is the type of disciplinary knowledge that is argued for in the *powerful knowledge* discourse. Powerful knowledge has been described by McPhail and Rata (2016) as a body of knowledge that it is created by people, yet is objective because "provisional knowledge is subject to rules and procedures which continuously test knowledge claims" (p. 55). This also means that the power and limitations of knowledge and its certainty only can be appreciated as long as the actual lines of reasoning, internal logic and methods are understood. Under this view, inquiry-type work that allows students to practise these skills would support the development of disciplinary knowledge. The authority of knowledge and the intellectual authority arising from the understanding of, and ability to practice, these disciplinary procedures is what the liberal educators of the 19th century promoted when they introduced aspects of epistemic development to pedagogy.

It seems as though not much has changed then, since the 19th century. Many education researchers support epistemic development for the same reasons as then: to gain intellectual authority. The means by which to effectively accomplish this appears to involve learning about the *processes* associated with a disciplinary field. Assumptions about knowledge – that is, whether or not a discipline explains an objective or subjective reality - arise from these processes, and therefore the assumptions alone are meaningless.

If the importance of epistemological processes to the development of epistemological understanding is accepted then it follows that in science epistemic development is best promoted by providing students with numerous opportunities to carry out science inquiries during a science course. This conclusion is consonant with the findings of other researchers into effective methods for *nature of science* instruction, who have shown the importance of students' reflections on the *nature of science* tenets during practical tasks (Khishfe, 2012a; Quigley et al., 2010). While this appears to be an attainable aim, the findings of the present paper suggest that, during science inquires students should focus on knowledge-generative processes and principles, such as the concept of evidence, the reliability and validity of investigations, uncertainty and the explanatory power of theories based on findings. Table 5.2 provides a comprehensive summary of the knowledge-generative processes that should be taught to support epistemic development. These concepts, associated with the science process, should underpin the discussion around any theoretical assumptions about the *nature of science* or the *nature of scientific knowledge* - which better captures the intent of this construct. Furthermore, the content of a science course should be organised *around* inquiries, rather than the content being supported by simple experiments in demonstration of a concept. This is not dissimilar to the way in which scientists apparently conceptualise the *nature of science* tenets: in relation their own inquiry processes, formulated based on their own experiences, practices and logic inherent in scientific inquiry. Emphasis placed on science inquiry would mean that students are provided with opportunities to test hypotheses and theories, evaluate their own and others' findings in terms of the power and limitation of the claims, therefore to the learn ways of thinking associated with the science discipline. This, 'powerful way of thinking' is the cornerstone of intellectual authority.

APPENDICES

Appendix 1: Item-by-item references for the instrument

Section 1 - The *Nature of science*

Part A Empirical

Questions	Sources
1. Once a scientific theory is proven then it becomes a scientific fact and does not change.	F. Abd-El-Khalick and Akerson (2004)
2. Scientific theories are always based on direct observations.	F. Abd-El-Khalick and Akerson (2004)
3. Scientific claims and theory based on inferences (about non-observable phenomena) and direct observations can be equally valid.	Lederman et al. (2002)
4. Science is fact based, so theories are not based on opinions, personal bias, or individual views.	Lederman et al. (2002)
5. Observed facts are used to prove that theories are true.	Lederman et al. (2002)
6. Science answers questions and is giving us absolute proof.	Eastwood et al. (2012)
7. Science knowledge is obtained through data collection, observation and inference.	Eastwood et al. (2012)

Part B Tentative

Questions	Sources
1. Scientific knowledge is certain and set in stone.	F. Abd-El-Khalick and Akerson (2004)
2. Scientific knowledge does not change once it is established.	Lederman et al. (2002)
3. Scientific theories can change, given new evidence or interpretations.	Eastwood et al. (2012)
4. If a scientific theory has been supported by evidence time and again, by numerous scientists, then it will definitely not change.	Eastwood et al. (2012)
5. In science we are never completely sure about anything, because new evidence can always call a theory or law into question.	Eastwood et al. (2012)
6. If you observations or experimental results support a theory over and over again, then that theory is proven to be true.	Eastwood et al. (2012)

Part C Theories vs. laws

Questions	Sources
1. Scientific laws describe quantitative relationships between measurable characteristics.	Lederman et al. (2002)
2. Scientific theories are explanatory models of natural phenomena based on observations.	Lederman et al. (2002)
3. Theories became laws after being repeatedly supported by observations or experiments.	Lederman et al. (2002)
4. The difference between a scientific law and a scientific theory is that a law has been proven to be true, but a theory might still be proven false.	Lederman et al. (2002)
5. A defining characteristic of a scientific theory is that is no	

way to conclusively prove it.	F. Abd-El-Khalick and Akerson (2004)
6. In science, a hypothesis is weaker than a theory and a theory is weaker than a law.	F. Abd-El-Khalick and Akerson (2004)
7. A scientific theory is a concept that has considerable evidence behind it and has endured the attempts to disprove it.	Lederman et al. (2002)

Part D Scientific method

Questions	Sources
1. The scientific method is a way of testing hypotheses.	Lederman et al. (2002)
2. Scientific method always follows the same steps.	Lederman et al. (2002)
3. Scientists know that they have the right answer to a research question if they have followed the scientific method.	Lederman et al. (2002)
4. A scientific inquiry involves observations, comparisons, measurements, tests, hypothesising, theory construction and explanations, but there is no particular sequence that these activities must follow.	Lederman et al. (2002)
5. Science requires following a step-by-step method to reach a valid conclusion.	Lederman et al. (2002)

Part E Experimentation

Questions	Sources
1. An experiment is a sequence of steps performed to test a proposed theory.	Lederman et al. (2002)
2. An experiment does not a prove theory or a hypothesis. Rather, it either refutes or adds validity to a theory.	Lederman et al. (2002)
3. Any process that involves the collection of data is an experiment.	Lederman et al. (2002)
4. Experimentation does not necessarily require manipulation of variables.	Lederman et al. (2002)
5. Scientists should not have any bias or prior opinion about the outcome of an experiment, or that experiment will not be valid.	Lederman et al. (2002)
6. Scientists usually have a preconceived idea the findings in an experiment.	Lederman et al. (2002)
7. Experiments are not always needed because some theories cannot be confirmed by direct experimentation.	Lederman et al. (2002)
8. Science knowledge is solely established by experiments.	Lederman et al. (2002)
9. Many theories - e.g., the theory of evolution - cannot be experimentally tested. Therefore the validity of such theories cannot be established.	Lederman et al. (2002)
10. Indirect evidence is used to establish the validity of the theories based on unobservable phenomena..	Lederman et al. (2002)

Part F Theory laden

Questions	Sources
1. If sufficient data were available there would be no, controversy over scientific theories. is	F. Abd-El-Khalick and Akerson (2004)
2. Scientific controversy can arise from different interpretations of the same data.	F. Abd-El-Khalick and Akerson (2004)

3. Different scientists may make different interpretations of observations and experiments.	F. Abd-El-Khalick and Akerson (2004)
4. Scientists think differently to one another, just like all people do. Therefore different scientists may come up with different interpretations of the same observations and experiments.	Lederman et al. (2002)
5. When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data.	F. Abd-El-Khalick and Akerson (2004)

Section 2 - Scientific Argumentation

Questions	Sources
1. Experiment design	Glaesser et al. (2009)
2. Quality of data	Glaesser et al. (2009)
3. Quality of data	Hind et al. (2001)
4. Quality of data	Hind et al. (2001)
5. Use of evidence	M. Jiménez-Aleixandre et al. (2009)

Appendix 2: The final version of the survey

Science Survey

Title of project: The development of scientific argumentation skills and science epistemology in senior high school courses: a quantitative study

Consent

Read the following statements and indicate your consent below by ticking the boxes.

Any information you provide will be kept confidential to the researcher and the supervisor. The results will not use your name, and no opinions will be attributed in any way that will identify you.

The data you provide will not be used for any other purpose or released to others without your written consent.

One or more articles based on the research findings will be submitted for publication in scholarly journals.

You may withdraw yourself (or any information you have provided) from this project before 15 November 2015 without giving a reason as long as you notify the researcher by email.

☐I have been given an explanation of this research project and have understood what it means. I have had an opportunity to ask questions and have them answered to my satisfaction.

☐I consent to the use of my NCEA Science results in this research (optional).

☐I agree to take part in this research.

____

Signature

About you

Answer questions as they relate to you. For answers, fill in the blanks tick or the box or boxes most applicable to you.

Your name [ ]

Your current level of study ☐Year 11 ☐Year 12 ☐Year 13☐Other(Specify)_____________

Your gender ☐Male ☐Female

Science subject(s) you are currently studying ☐Science ☐Biology ☐Chemistry ☐Physics ☐Earth Science ☐None Other (Specify)________________________

NCEA endorsements in science

	NCEA Level 1		NCEA Level 2		NCEA Level 3	
	Merit	Excellence	Merit	Excellence	Merit	Excellence
Science	☐	☐	☐	☐	☐	☐
Biology	☐	☐	☐	☐	☐	☐
Chemistry	☐	☐	☐	☐	☐	☐
Physics	☐	☐	☐	☐	☐	☐
Earth Sci.	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

Specify other science subject(s) ____

you gained
endorsement in

Nature of science

Indicate your agreement or disagreement with each statement by ticking one of the boxes next to the statements.

17. Scientific theories are always based on direct observations. ☐Agree ☐Disagree
18. Scientific theories can change given new evidence or interpretations of data. ☐Agree ☐Disagree
19. Scientific theories based on indirect observations are less valid than those based on direct observations. ☐Agree ☐Disagree
20. The scientific method is a method of testing hypotheses. ☐Agree ☐Disagree
21. Any process that involves the collection of data is an experiment. ☐Agree ☐Disagree
22. The difference between a scientific law and a scientific theory is that a law has been proven to be true, but a theory might still be proven false. ☐Agree ☐Disagree
23. Scientific knowledge is solely established by experiments. ☐Agree ☐Disagree
24. If a scientific theory has been supported by evidence time and again, by numerous scientists, then it becomes a scientific fact and does not change. ☐Agree ☐Disagree
25. Scientific method always follows the same steps in the same order. ☐Agree ☐Disagree
26. Experimentation does not necessarily require manipulation of variables. ☐Agree ☐Disagree
27. If sufficient data were available there would be no controversy over scientific theories. ☐Agree ☐Disagree
28. Scientists know that they have the right answer to a research question if they have followed the scientific method. ☐Agree ☐Disagree
29. Different scientists may make different interpretations of observations and experiments. ☐Agree ☐Disagree
30. A scientific theory or hypothesis cannot be proven to be true. ☐Agree ☐Disagree
31. Scientific theories are fact-based and not influenced by scientists' opinions. ☐Agree ☐Disagree
32. When there is a controversy in science it is always because some scientists have not followed scientific procedures correctly, resulting in them collecting inaccurate data. ☐Agree ☐Disagree

Scientific Argumentation

In this section you will find four short scenarios followed by statements referring to the scenario. These scenarios describe different situations where scientific evidence is gained by various means.

1. **Factors affecting photosynthesis**

Some groups of students carried out experiments to examine the factors affecting the rate of photosynthesis on Elodea *sp*. plants. The rate of photosynthesis is determined by the number of oxygen bubbles formed by the Elodea *sp*. plants. The efficiency of photosynthesis can be measured by the amount of oxygen bubbles formed in a given amount of time. Three factors were investigated: light intensity (distance from light source), colour of light and temperature. The groups of students set up investigations with the conditions listed below. All of the groups measured the number of bubbles produced over the same period of time.

	A	B	C	D	E	F	G	H	I	J
Temperature (^{o}C)	24	24	22	24	22	20	24	22	24	22
Light intensity/distance from light source (cm)	10	10	20	30	10	30	10	30	10	30
Colour of filter	blue	red	blue	red	blue	red	yellow	blue	green	red

33. Light intensity/distance from light source

Which groups’ data should be compared to find out the effect of light intensity on the rate of photosynthesis?

☐A, C, D

☐E, F, H, I

☐C, E, H

☐D, F, H, J

☐This cannot be decided by comparing the groups' data.

34. Temperature

Which groups’ data should be compared to find out the effect of temperature on the rate of photosynthesis?

☐A, C, F

☐F, G, H

☐B, C, F

☐D, F, J

☐This cannot be decided by comparing the groups' data.

2. The effect of fertilisers on plant growth

Two groups were going to find out how the amount of fertiliser affects the growth of plants. Each group set up an experiment where 5 plants where given different amounts of fertiliser. Their experiment and the measurements are shown in the tables below.

Group A

Plant	Added fertiliser (g)	Height of plant (cm)
1	3	5
2	6	6
3	9	7
4	12	9
5	15	10

Group B

Plant	Added fertiliser (g)	Height of plant (cm)
1	0	3
2	25	15
3	50	7
4	75	3
5	100	0 (dead)

Indicate your agreement or disagreement with each statement by ticking one of the boxes next to the statements.

35. On the basis of Group A's experimental data the hypothesis that “the more fertiliser you add the better plants grow” cannot be rejected.	☐Agree	☐Disagree
36. On the basis of Group B's experimental data the hypothesis that “plants grow best when given 25g fertiliser” cannot be rejected.	☐Agree	☐Disagree
37. Both groups need to refine the range of independent variables used in their experiment.	☐Agree	☐Disagree
38. The reliability of the data could be improved by repeated measurements in both groups' investigation.	☐Agree	☐Disagree
39. These experiments are not reliable because the two groups reached different conclusions.	☐Agree	☐Disagree
40. The validity of these experiments cannot be decided because there is no information about how other variables were controlled.	☐Agree	☐Disagree
41. Neither group used a control condition.	☐Agree	☐Disagree
42. Group A’s conclusion, “the more fertiliser you add the better plants grow”, is supported by the two groups' combined data.	☐Agree	☐Disagree

3. Nut oil

Two groups of nutritionists have been asked to measure the mass of 100 cm3 of nut oil. Each group takes nine samples of 100 cm^3 of the oil from a large container and weighs each sample. These are their results sorted into ascending order:

Measurements in grams:

Group A	81.9	83.5	86.5	87.1	87.3	87.5	87.5	90.5	92.1	average 87.1
Group B	84.9	85.7	86.6	86.9	87.0	87.3	88.2	88.5	88.8	average 87.1

Indicate your agreement or disagreement with each statement by ticking one of the boxes below the statements.

43. We can be more confident in Group A's result because two of their measurements agree. ☐Agree ☐Disagree
44. We can be more confident in Group A's result because one of their measurements is the same as their average. ☐Agree ☐Disagree
45. We can be more confident in Group B's result because the range between the largest and the smallest measurement is less. ☐Agree ☐Disagree
46. We can be equally confident in either group's averages because both sets of measurements have the same average. ☐Agree ☐Disagree

4. Copernicus' remains

In August 2005 a team of archaeologists dug up the floor of Frombork Cathedral and found some bones and a skull with several teeth remaining. After further examination of the remains they claimed that the remains belonged to Nicolaus Copernicus (1473-1543) the famous astronomer, who died in Frombork, Poland. The following evidence supports the theory that the remains found are those of Copernicus.

- There are resemblances between the skull and Copernicus' portraits, such as broken nose and scar above the left eye.
- Forensic studies show that the remains belonged to a man aged around 70 years.
- Computer graphic reconstruction of the face bore a great resemblance to a portrait of Copernicus.
- The remains' DNA was analysed and compared to four hairs retrieved from the pages of the book Calendarium Romanum Magnum, once owned by Copernicus. The DNA test showed that two hairs and the bones belonged to the same individual.

Indicate your agreement or disagreement with each statement by ticking one of the boxes below the statements.

47. All of this evidence together proves that the remains belong to Copernicus. ☐Agree ☐Disagree
48. All of the evidence without the DNA testing wouldn't be enough to prove the identity of the remains with great certainty. ☐Agree ☐Disagree
49. Since DNA testing can prove with a 99% certainty that the remains and the two hairs belonged to the same person; this alone is enough evidence to prove that these are Copernicus' remains. ☐Agree ☐Disagree
50. The individual pieces of evidence one-by-one are not very relevant; rather the accumulation of these pieces of evidence gives more reliability to the claim. ☐Agree ☐Disagree

Appendix 3: Differences between year levels in the different subject areas

In order to identify whether the same tendency, a lack of difference between the epistemological views of Year 12 and 13 students true at the different disciplines several repeated-measure analysis of variance was conducted as time (term 1 vs. term 3) as the within-subject factor and treatment (science students vs. no science study) as a between-subject factor for each science discipline.

Both chemistry and biology students' scale location declined significantly during the three terms, but there was no significant difference between year levels in terms of neither theory development scores nor rate of progression during the year. The biology the sample size was 55 (n=55) and 57 (n=57) at Year 12 and 13 respectively. Group means varied significantly as a main effect of time; F(1, 110) = 12, 41, p = .001 and there was no main effect of year level, F(1, 110) = 1.09, p = .3 nor interaction between time and year level F < 1, p = . 94. The chemistry students' sample size for this variable was 50 (n=50) at Year 12 and 51 (n=51) at Year 13 level. There was a main effect of time; F(1, 99) = 4.139, p = .045. There was neither significant effect of year level; F(1, 99) = 2.272 nor main combined effect of time and year level; F < 1, p = .446.

In physics and science there was neither a significant difference between year levels, nor the progression over time was noteworthy. The physics students' sample size was 51 (n=51) and 49 (n=49) for Year 12 and 13 students respectively. There was no main effect of time; F(1, 98) = 1.581, p = .221, no significant effect of year level; F < 1, p = .603 and no significant interaction effect of time and year level; F(1, 98) = .212. There was no significant interaction between time and year level; F < 1, p = .938. There were 1 (n=1) Year 11, 14 (n=14) Year 12 and 17 (n=17) Year 13 students in the science sample. There was no significant effect of either time; F < 1, p = .755, or year level; F < 1, p = .553, or significant combined effect; F <

1, $p = .985$. This means that the difference between scores of students studying at different levels cannot be attributed to the levels of study for most of the science disciplines. This disconfirms the hypothesis that Year 13 students have a more advanced epistemic view and that they would progress at a higher rate compared to Year 12 students.

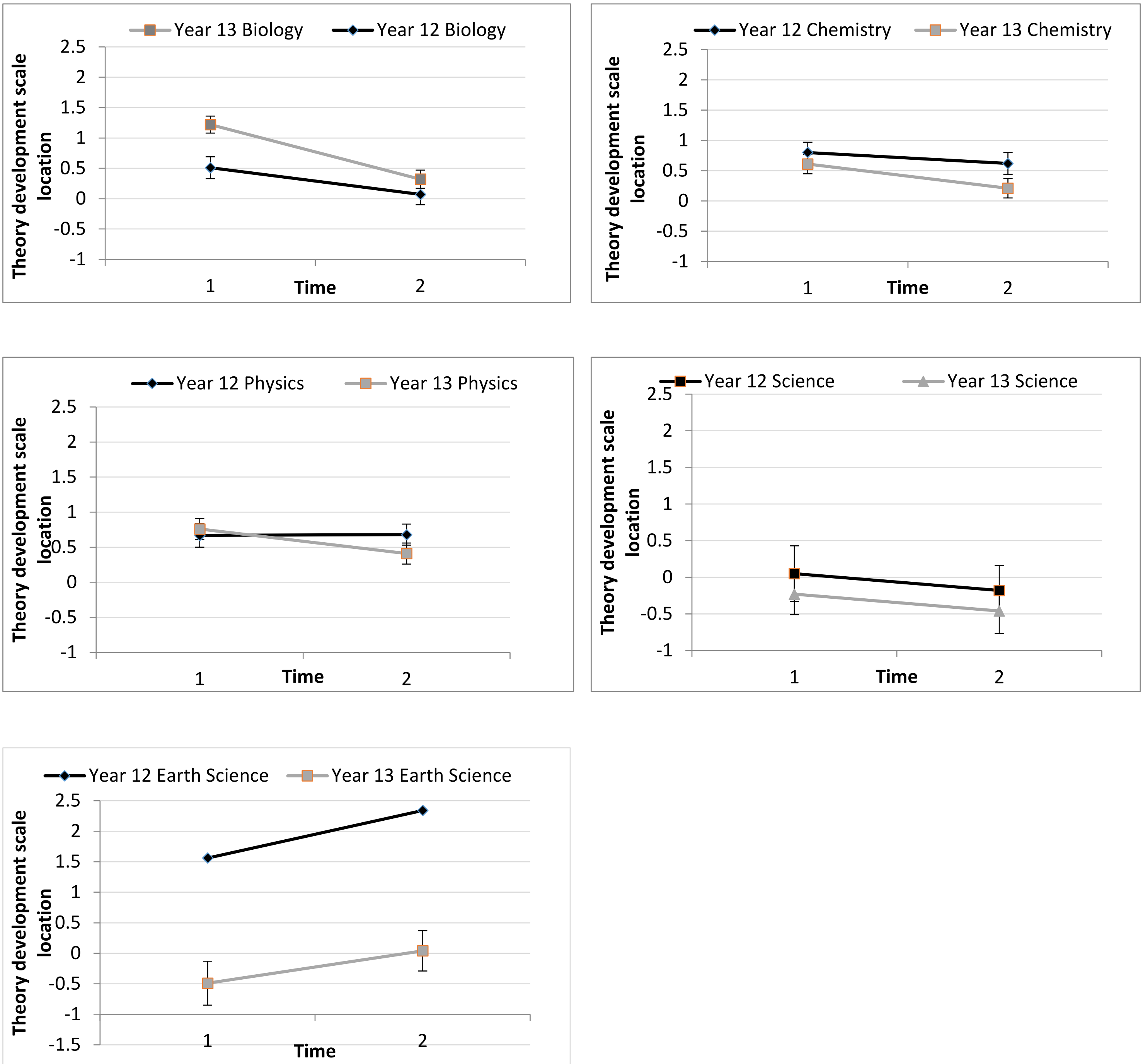


Figure A1: Change of scale location over time for the *theory development* variable in various science disciplines (biology, chemistry, physics, science and earth science) at Years 12 and 13.

For the *data collection* variable similar results were evident. In biology, chemistry and physics there was a main effect of time evident, which indicates that the decrease over time during three terms of science courses is statistically significant. However, the evidence did not support neither of the hypotheses that Year 13 students would more advanced understanding of data collection, nor that they would progress at a higher rate compared to Year 12 students. The sample size in biology was 54 (n=54) at Year 12 and 57 (n=57) at Year 13 levels. The within subject effects showed significant main effect of time; $F(1, 109) = 9.697$, $p = .011$, between subject effects it showed no significant main effect of year level ; $F < 1$, $p = .443$, and no significant interaction of time and year level ; $F < 1$, $p = .683$ was apparent. Chemistry students' sample size was 48 (n=48) at Year 12 and 51 (n=51) at Year 13 levels. The within subject effect showed significant effect of time; $F(1, 97) = 6.238$, $p = .014$, no significant main effect of year level; $F < 1$, $p = .84$, and no significant combined effect of time and year level; $F < 1$, $p = .801$. There were 48 (n=48) Year 12 and 51 (n=51) Year 13 physics students in the data collection sample. Means varied significantly as a main effect of time; $F(1, 97) = 11.29$, $p = .001$. There was neither significant effect of year level $F < 1$, $p = .63$, nor significant combined effect of time and year level; $F < 1$, $p = .35$.

In most science subjects there was no significant difference between students studying at different levels and the completion of courses and levels of study did not have a combined effect. The only exceptions were science and earth science, as the Year 13 students' scores were significantly higher compared to that of Year 12 students. In biology, chemistry and physics the level of data collection conceptions declined during the year, despite the completion of science courses. This again refutes the hypothesis that Year 13 students would progress at a higher rate compared to Year 12 students studying biology, chemistry, physics or science. The hypothesis is confirmed, however, for earth science coursework. In science there was neither main effect of time; $F < 1$, $p = .553$, nor main combined effect of time and year level; $F(2, 29) = 1.28$, $p = .308$ in science. In contrast, there was a significant effect of year level; $F(2, 35.223) = 3.785$, $p = .035$. In the earth science subject area there was no significant effect of any of the factors time, year level and combined effect of time and year level, $F(1,10) = 1.63$, $p = .234$; $F < 1$, $p = .819$ and $F(1, 21.493) = 4.038$, $p = .072$ respectively.

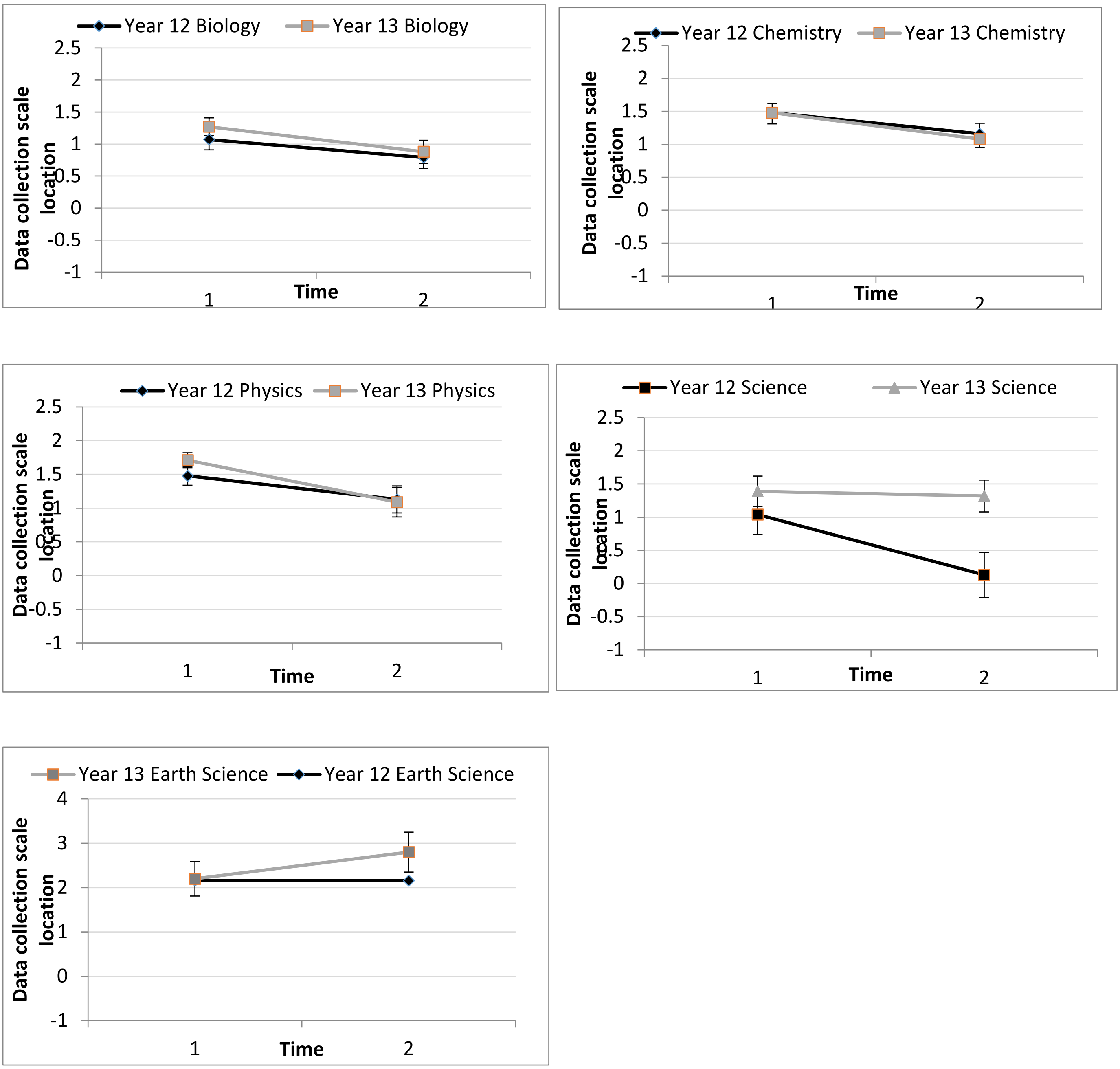


Figure A2: Change of scale location over time for the *data collection* in various science disciplines (biology, chemistry, physics, science and earth science) at Years 12 and 13.

Summary of differences between year levels

There was no evidence to support the hypothesis neither that Year 13 students would have a more advanced epistemic view nor that they would progress at a higher rate for either variable in biology, chemistry or physics compared to Year 12 students. The levels of study contributed to the observed differences only in the case of earth science and science, however, the sample size in each case were too small to yield reliable results.

In core sciences, biology, chemistry and physics, students understanding of concepts associated with both *theory development* and *data collection* variables decreased during the three terms significantly.

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