

Science investigation that best supports student learning: Teachers' understanding of science investigation

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Internationally, learning science through investigation is promoted as a preferred pedagogical approach. Research presented takes a view that such learning depends on how teachers understand science investigation. Teachers' understanding of science investigation was an aspect of an interpretive case study of the phenomenon of science investigation exploring the links between learning, motivation and assessment in year 11 science. Data were collected through a population survey of year 11 science teachers (n=165) in the greater Wellington region through a postal questionnaire (response rate 61%). In addition, all year 11 science teachers in a typical coeducational, middle size, urban secondary school were interviewed (n=10). Findings suggest that science investigation that best supported student learning was understood to include experiments, scientific method, and fair testing, and that few teachers demonstrated understanding of an open-ended science investigation. Teachers' responses indicated the influence of assessment requirements of a linear and sequential fair testing type of investigation. This has implications for teaching investigation as required by the curriculum, and student learning for assessment rather than an understanding of the nature of scientific investigation.

Key words: science investigation, teacher understanding of science investigation, scientific inquiry, nature of science, procedural knowledge

Introduction

Teaching science is complex and demanding if the aim of teaching science in schools is to develop conceptual understanding, procedural knowledge, understandings of the nature of science, usefulness, and associated socio-scientific issues that conceptualise a scientifically literate individual (Moeed, 2010; Schwartz, Lederman, & Crawford, 2004). This paper focuses on just one aspect of this challenge, practical work and specifically investigation or scientific inquiry. Science education researchers agree that practical work has a place in science learning (Abrahams & Millar, 2008; Hodson, 2009; Millar, 2004). Other science educators argue that many benefits accrue from engaging students in practical activities in science (Hofstein, 2004; Hofstein, Kipnis, & Kind, 2008; Lunetta, 1998; Woolnough, 1991). Some also suggest that often

students have not properly developed investigative skills and, therefore, there is little meaningful learning from these activities (Hodson, 1990; Roberts & Gott, 2004a).

At the start of this millennium, the quest for achieving a common goal, encouraging teachers to use scientific inquiry (science investigation) as a pedagogical approach led to a big commitment of resources for developing innovative curricula, building teachers' skills and systemic reform to support science teaching and learning in the United States (Minner, Levy, & Century, 2010), Europe (European Commission, 2007), and Australia (Goodrum & Rennie, 2007). Internationally, teachers are being required to implement inquiry learning programmes and Hume and Coll (2008) state that "to design and deliver such programmes teachers first have to be cognizant of procedural knowledge in science (i.e., how scientists think and work) and what constitutes authentic scientific inquiry (investigation)" (p. 1201). Teachers are advised to be focused and explicit about the purpose of the investigation and share it with their students (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000). Secondary students do not develop an understanding of scientific investigation as a process of knowledge development by just being involved in investigative activities (Trumbull, Bonney, & Grudens-Schuck, 2005). Lotter, Singer, and Godley (2009) argue that the implementation of an investigative pedagogical approach and teaching of nature of science starts with teachers who understand and who can teach students using these approaches. At this point it would be useful to clarify that the terminology scientific inquiry is used in the United States and science investigation in the United Kingdom, Australia and New Zealand.

During this study of science investigation that explored the links between learning, motivation and internal assessment of science investigation, it emerged that teachers may not understand what science investigation is, which may influence the way in which they teach it (see Moeed, 2010). In New Zealand, although the curriculum and assessment were developed independently, teachers have negotiated the contested space of the curriculum and assessment reform. Here it is argued that for students to learn and practise science investigation it is critical for teachers to have a sound understanding of it.

Theoretical Perspectives

First, relevant literature on science teacher understandings is presented followed by recent perspectives on teacher understanding of science investigation. The second section frames the many types of practical work and differentiates inquiry and investigation. The third section presents the New Zealand context. Finally, theory with respect to scientific method, fair testing, experiments and investigation is presented as applied to the framework for analysis of the data.

Teacher Knowledge and Understanding

According to Shulman (1986), "Those who can, do. Those who understand, teach" (p. 14), which is a thoughtful statement that reflects the significance of teacher understanding of teaching. Later, Shulman (1999) articulated the many forms of knowledge a teacher possesses including content, pedagogical, curriculum, pedagogical content and the knowledge of learners, educational contexts, purposes and values. Researchers have extensively used his framework of pedagogical content knowledge which is seen as a combination of content and teaching knowledge that teachers use to apply various teaching approaches to achieve learner understanding of content (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001) and for identifying "what it is that a teacher knows and is able to do" (Berry, Loughran, & van Driel, 2008, p. 1275). More broadly, Verloop, van Driel, and Meijer (2001) describe teacher knowledge and teacher practical

knowledge as “the whole of the knowledge and insights that underly teachers’ actions in practice” (p. 446). Connelly and Clandinin (1985) identify teacher knowledge as personal knowledge, whereas Schwab (1971) calls it the wisdom of practice. Shimahara (1998) takes a more applied view and sees teacher knowledge as professional craft knowledge. Teacher understanding of science investigation is the focus of this paper.

Teacher Knowledge and Understanding of Science Investigation

International literature indicates that to implement an investigative approach teachers need to have a sound understanding of the investigative process (National Research Council, 2000). Teachers’ understanding of science investigation is fundamental to their teaching of it (Anderson, 2002). However, there is little empirical research that focuses on teachers’ investigative abilities (Davies, Petish, & Smithey, 2006). Little is known about teachers’ views about the goals and purposes of science investigation, how they carry it out, or what motivates teachers to use this to undertake a “more complex and difficult to manage form of instruction” (Keys & Bryan, 2001, p. 636). Crawford (2000) argues that teachers require a high level of pedagogical content knowledge and sound understanding of the nature of science and of how to be a coach and a mentor. Windschitl (2003), in a study of six pre-service teachers, found that some had a realistic view of investigation while others viewed it as a linear process that requires following a series of steps. Windschitl, Thompson, and Braaten (2007) argue that research and policy have had little impact on practices of teaching investigation in schools because students develop “deep-seated beliefs about scientific practice” in their secondary education. During their schooling, students develop the belief that there is a step-wise scientific method to be followed to arrive at a conclusion; this is how scientists generate new knowledge. They explain that students gain a limited understanding of scientific reasoning and practice because of pedagogical approaches that focus on student activity rather than understanding of scientific ideas, and suggest that some go on to become teachers who “enculture” the next generation with simplified and questionable understandings of the investigation process (Windschitl et al., 2007, p. 949). From their extensive review of literature, Davies et al. (2006) concluded that teachers had a naïve view of the nature of science including how science is conducted, and in one study pre-service teachers believed in a universal scientific method (Abd-El-Khalick, 2001; Windschitl et al., 2007). Presently, though there is research pointing to “recipe practicals” being a common practice in New Zealand schools (Hipkins et al., 2002), little is known about teachers’ understandings of science investigation. Hence, the purpose of this research was to explore science teachers’ understanding of science investigation.

The Nature of School Science Investigation

The following presents and clarifies the terminology used internationally in relation to inquiry and investigation.

Inquiry and investigation

Internationally, the term inquiry has featured prominently in the recent science curricula and refers to three different types of activities: scientific inquiry, inquiry learning, and inquiry teaching. *Scientific inquiry* “refers to characteristics of the scientific enterprise and processes through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge” (Schwartz et al., 2004, p. 612). It is what scientists do; they conduct open-ended investigations drawing upon both theoretical and procedural understanding in a purposeful way to achieve specific goals (Hodson, 1992;

Hume & Coll, 2008). It has been argued that school science investigation should reflect science as practised by contemporary scientists but it is acknowledged as not being a practical option for both resource and knowledge reasons (Grandy & Duschl, 2008). Focusing on the distinction between practising a discipline and learning about it, Kirschner, Sweller, and Clark (2006) posit that “the way an expert works in his or her domain (epistemology) is not equivalent to the way one learns in that area (pedagogy)” (p. 78). Scientific investigation refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (National Research Council, 2000, p. 23). This definition is based on understanding how science proceeds and is independent of educational processes (Anderson, 2002).

Inquiry learning is about how students learn, actively thinking and delving into procedures that scientists follow to carry out investigations to answer questions (Minner et al., 2010). *Inquiry learning* is considered to be an active learning process, something that students “do”. It is implied that inquiry learning should reflect the “nature of scientific inquiry” (Anderson, 2002, p. 2). Hodson (2001) argues that it is important that students engage in, and develop expertise in, scientific inquiry and problem solving.

Inquiry teaching is a pedagogical approach that teachers employ to deliver inquiry-based curricula using inquiry teaching and learning approaches. In the United Kingdom, discovery learning was applied in the Nuffield projects where the focus was on learning science ideas through practical work (Glaesser, Gott, Roberts, & Cooper, 2008). Inquiry teaching is not necessarily science inquiry; it may be an extended inquiry into a question of interest to the students in any area.

The focus of this paper is on scientific inquiry in secondary school but the term science investigation is used instead of scientific inquiry because this is the term used in the New Zealand curriculum. The many ways in which practical work is described in the literature and implemented in the classroom are explored below where practical work is considered to be all science activities that students engage in that require them to manipulate materials to learn science – sometimes referred to as laboratory work (Millar, 2004).

Science investigation (Open ended investigation)

Scientific investigation is a holistic approach to learning science through practical work (Woolnough, 1991). “The aim of science investigation is to provide students opportunities to use concepts and cognitive processes and skills to solve problems” (Gott & Duggan, 1996, p. 26). Millar (2010) has defined investigation as:

Practical activity in which students are not given a complete set of instructions to follow (a “recipe”), but have some freedom to choose the procedures to follow, and to decide how to record, analyse and report the data collected. They may also (though this will not be taken as a defining characteristic) have some freedom to choose the question to be addressed and/or the final conclusion to be drawn. Like “experiments”, “investigations” are a sub-set of “practical work”. (p. 2)

Students gain most from science investigation when they “discuss expectations, observations, conclusions, theories, and explanations before, during, and after conducting the activity” (Patrick & Yoon, 2004, p. 319). Millar (2004) agrees with the importance of discussion before and after the investigation. Learning through investigation needs to be seen as a recursive process rather than a constrained procedure. This recursive process is promoted in *Science in the*

New Zealand Curriculum (Ministry of Education, 1993, p. 47). The degree to which the student has control over defining the problem, choosing the methods, and arriving at solutions dictates whether a practical activity is an open investigation or a closed practical activity (Simon, Jones, Fairbrother, Watson, & Black, 1992).

Investigative process includes four phases: a design and planning phase, a performance phase, a reflection phase, and a recording and reporting phase (Hodson, 2009). In a scientist's work, these phases take place not sequentially but concurrently; for example, as the scientists plan investigation they are already evaluating the methods they are going to follow (Hodson, 2009). In school science, open-ended investigation differs from other kinds of practical work in that students are given few instructions about data collection, processing, and analysis when they are required to solve a problem. A student looks at the problem presented to them, and uses their existing contextual and procedural understanding to first come up with a hypothesis. This hypothesis is not a random guess but is based on thought and current understanding. They plan and carry out the investigation and then, as the investigation proceeds, the student evaluates the process and makes any necessary changes. The decision making, evaluation and modification are essential to the process of investigating and make the principal difference between an investigation and a practical task (Gott & Duggan, 1996; Roberts, 2009). Focussing on using science investigation to develop conceptual understanding, carrying out a complete investigation of this kind enables students not just to do science but to learn science concepts and understand the nature of science (Hodson, 1990, 2009). Students need both the understanding of science concepts (substantive knowledge) and skills (understanding of science procedures) to successfully carry out a science investigation (Abrahams & Millar, 2008; Roberts & Gott, 2003). In Australia, Tytler (2007), calling for "*Re-imagining science education*," suggested that "investigative design should encompass a wide range of methods and principles of evidence including sampling, modelling, field-based methods, and the use of evidence in socio-scientific issues" (p.64). Tytler (2007) asserts that students should decide the questions they want to investigate and that "investigations should exemplify the way ideas and evidence interact in science" (p. 64).

There have been significant developments in the field of school science investigation and assessment of science investigation over the last decade which have included the identification of problems with validity and reliability of the assessment of investigation (Roberts & Gott, 2004a, 2006), evaluation of evidence provided by the data collected by students, role of argumentation (Roberts, 2009), and creativity in science investigation (Gott, Duggan, & Hussain, 2009).

The Scientific method

In the 1950s, with continuing issues of low uptake of science courses in Australian universities, the use of the scientific method in a *distilled essence* was proposed so school children could understand it and apply it to other fields as well as science (Bradley, 2005). Australian science teachers embraced the scientific method and in some Australian states scientific method was listed among the objectives of the course (Bradley, 2005). Scientific method is described as a series of steps which include: observing, defining the problem, gathering reliable data, selecting an appropriate hypothesis to explain the data, planning, carrying out experiments or observations to test the hypothesis, and drawing a conclusion in support or otherwise of the tested hypothesis (Bradley, 2005; Lunetta, Hofstein, & Clough, 2007; Wong, Hodson, Kwan, & Yung, 2008). Most critics of a scientific method consider following ordered steps inadequate as a description of scientific practice or as a guide to instruction (Hodson, 1996; Lederman, 1998; Tang, Coffey, Elby, & Levin, 2010; Windschitl, 2004; Wink, 2005).

Scientists carry out investigations in a variety of ways; they do not follow a particular method but many different methods depending on the nature of the investigation. In Mahootian and Eastman's (2008) view, most scientists agree that there is no single *scientific method* and that a simplistic representation of how scientists investigate is misguided. Drawing upon the work of Knorr-Cetina (1999) in comparing two different scientific laboratory cultures of high energy physics and molecular biology, Davies (2005) argues that there are differences "in practice between science disciplines, and between individual topics within disciplines" (p. 3). Davies attributes these differences to the nature of the questions asked, and the theories, methods and equipment used. Other critics of the scientific method have argued that "decontextualised accounts overlook the guiding role and interpretive nature of scientific theory" (Tang et al., 2010, p. 29). Such an approach overlooks how these steps are taken into account in relation to each other (Windschitl et al., 2007). Mahootian and Eastman (2008) cite Suppe (1998) who points out that the scientific method is useful in:

providing guidelines for *reporting* the results of scientific research, that is, to provide scientific explanations of the phenomena under investigation while maintaining consistency of format and communication protocols [and that] identifying science with such guidelines produces a sanitised and unreal view of science in practice. The neatness of the research report stands in stark contrast to the messiness of the process that produced it. (p. 64)

This notion of a framework to report findings of an investigation appear to be aligned with the manner in which the scientific method is set out in the introductory chapters of science text books used by students in junior science classes (Wong et al., 2008). An additional aspect of this commonly used scientific method is that "many students and teachers consider that making a hypothesis is an essential component of this stepwise generation of scientific knowledge" (Wong et al., 2008, p. 1427).

Lunetta et al. (2007) attribute the persistent use of the scientific method to a lack of confidence and limited understanding of the science ideas on the part of the teacher, while Windschitl et al. (2007) argue that scientific method enables teachers to manage practical work in overcrowded classrooms and allows an entire investigation to be completed in a lesson or two. That there is no single scientific method is in agreement with science education researchers including Hodson (1990), Wellington (1998), and Tytler (2007).

Fair testing

In a fair testing type of investigation a student is presented with a scenario, they identify a question, plan an investigation, control variables and manipulate a single variable, gather data, process the data, and come up with a conclusion. The assessed fair testing investigation requires an awareness of reliability. Fair testing is one of the six types of investigation proposed by Watson, Goldsworthy, and Wood-Robinson (1999) which include: 1, Classifying and identifying; 2, Fair testing; 3, Pattern seeking; 4, Investigating models; 5, Exploring; 6, Making things or developing systems. In Watson et al.'s (1999) view, the proposed six different types of investigation for school science cover a range of skills and give students the opportunity to gain an understanding of science ideas and how science works.

Experiment

Experiments are used to give the students a “feel for phenomena” and sometimes they are carried out to confirm a theory (Woolnough & Allsop, 1985, p. 4). Abrahams and Millar (2008) describe experiment as “a planned intervention in the material world to test a prediction derived from a theory or hypothesis” (p. 1947).

Skills

The curriculum (Ministry of Education, 1993) requires the teaching and learning of investigative skills of focussing and planning, data gathering, processing, and interpreting and reporting the findings, and further that students are to learn these skills and carry out complete investigations.

Issues with implementing an investigative approach

Implementing open-ended science investigations is problematic. “There are very few examples of successful implementation of extended investigation as part of the science curriculum in the context of ‘mass education’ where large numbers of teachers and students are involved” (Millar, 2004, p. 16). Millar argues that teachers have difficulty in coming up with enough projects for students to investigate and, as a result, investigations become routinised and “assessed investigation becomes almost the only investigation done” (2004, p. 16). A matter of concern is that teachers find it difficult to formulate questions that can be investigated (Van Rens, Pilot, & Van der Schee, 2010).

Teachers cite challenges that include lack of time, lack of confidence in their own ability to assess, along with safety and management issues (Tamir, 1989). In New Zealand, teachers report lack of resources, time restraints, inadequate facilities, and little technician support to repair and maintain equipment and set up laboratories as reasons for not using an investigative approach in their teaching (McGee et al., 2003).

Influence of teacher beliefs

Teacher beliefs influence and drive science teachers’ practice (Richardson, 1996). It is suggested that science teachers need to consider the underlying belief they have about teaching and learning science inquiry and that they should be given multiple opportunities to reframe and redefine their beliefs about inquiry instruction (Yerrick, Parke, & Nugent, 1997). Pajares (1992) argues that beliefs are often underpinned by personal experiences and are therefore difficult to change. On the contrary, Luft (2001) found that having student-centred beliefs could lead to a change in teacher practice. Windschitl et al. (2007), based on their research into the scientific method, argue that teachers’ belief of an “unproblematic procedural process is not only alive and well but dominates the conceptual frameworks that both novice and experienced teachers use to design investigative science experiences for students” (p. 942). The research reported here did not specifically investigate teacher beliefs.

The New Zealand Context: Curriculum and assessment requirements

Learning to investigate is a mandatory requirement of *Science in the New Zealand Curriculum* (Ministry of Education, 1993) and *The New Zealand Curriculum* (Ministry of Education, 2007). *Science in the New Zealand Curriculum* was the first national curriculum statement written for science across all levels of schooling in New Zealand and there were great expectations that its implementation would lead to better teaching and learning of science in New Zealand primary and secondary schools. The Curriculum Stocktake (McGee et al., 2003) highlighted the less than

adequate teaching of science investigation and influenced the placement of science investigation within the Nature of Science strand giving it prominence in *The New Zealand Curriculum* (Ministry of Education, 2007) which has been implemented in stages since 2008.

In New Zealand, since 2002, student ability to carry out a science investigation with direction has been assessed in year 11 (age 15+) for credits and grades towards National Certificate in Educational Achievement (NCEA) credits and grades at level one. The assessment is through Achievement Standard AS1.1. With the mandated requirement to teach and assess investigation teachers have adapted their teaching, and schools in New Zealand have developed processes for carrying out the assessment in year 11 where assessment is required for a large number of students. In a case study of science investigation *with direction* in New Zealand, Hume and Coll (2008) concluded that students in year 11 were acquiring a narrow view of science investigation as “fair testing”, and that although learning was taking place, students’ comments indicated they used rote learning and low level thinking. They have attributed their findings to the narrow curriculum experienced by students due to schools’ science teaching programmes which were influenced by the requirements of national assessment policy. In the United Kingdom, fair testing is a type of investigation that requires controlling of variables but in practice has been reduced to a formulaic approach implemented by teachers to fulfil the requirements of assessment (Author, 2010; Hume & Coll, 2008; Roberts & Gott, 2004b). Concern has been raised about the extent to which assessment dominates student thinking and action and that students had started to falsify results and create anomalous data in order to explain these to improve their grades (Keiler & Woolnough, 2002; Toplis & Cleaves, 2006). This raises the question of whether teachers understand science investigation to be an open-ended iterative process to answer a question identified by the learner or a linear and sequential process that requires students to find the answer to a question presented by the teacher as required for assessment, the answer to which may be obvious and already known to the student.

Theoretical frame

Present research was underpinned by the constructivist theory of learning. The fundamental constructivist belief is that knowledge must be constructed by the mental activity of the learner and cannot be transmitted (Driver, Asko, Leach, Mortimer, & Scott, 1994; Osborne & Freyberg, 1985). Constructivism presupposes that all new learning is acquired in relation to prior knowledge (Windschitl, 2003). Much research into learning in science in New Zealand, since the 1980s, has been informed by constructivist views of learning, and the literature draws upon social and personal constructivist views. Teacher understanding about which pedagogical approaches are likely to help students to grasp concepts, develop skills or understand about the nature of science is likely to influence how teachers teach and enhance student learning (Driver et al., 1994; Leach & Scott, 2003).

Constructivism as a theory of learning originated in the field of cognitive sciences and provides a basis for understanding how individuals incorporate new knowledge acquired from personal experiences into existing knowledge and then making sense of that knowledge (Ferguson, 2007; Tobin, 1990). Constructivism provides a framework for thinking about the ways in which learners engage and make sense of the objects around them (Bodner, Klobuchar, & Geelan, 2001; Ferguson, 2007). There are several different kinds of constructivism that have been reviewed by Geelan (1997) and Ferguson (2007). Personal constructivist (also called cognitive constructivist) theories focus on the individual’s personal construction of meaning (Driver, 1989). This theory does not acknowledge the social and cultural context of the learner (O’Loughlin, 1992). Solomon (1987) suggested that the social setting “makes an essential

difference to the learning situation, to how the task is perceived and even to the tools for thought that will be used” (p. 63). Learning is affected by the reflection on experiences we have, as well as from the reaction of others when we share our ideas. Solomon posits that we might not understand what we think until we can discuss it with others to gauge their views about our thoughts. The social constructivist view acknowledges the intra-domain nature of learning with both the social setting and the individual’s role in the construction of knowledge. In this research, learning is viewed as both personally and socially constructed, and from this perspective the role of the teacher is highly significant. Pedagogy based on constructivism requires an interaction between teacher and learner that includes eliciting of prior knowledge, exploration, and reflection.

Research Questions

The basic question posed was how year 11 science teachers understand “science investigation” and was expanded by asking the following questions:

1. What features make up a science investigation that would best support Year 11 student learning?
2. What is the role of science investigation in science teaching and learning?
3. What are teachers’ goals for student learning through science investigations?

Research Methodology and Methods

Qualitative research is interpretive, has a naturalistic orientation, and allows the use of multiple methods (Denzin & Lincoln, 1994, 2005; Guba & Lincoln, 1981). Within a qualitative research paradigm, the research took a case study approach and studied the phenomenon of science investigation. The intention was to understand investigation, the phenomenon of interest through those who practise it in their unique contexts, and through the interactions that take place in that setting (Merriam, 1998).

The data presented were gathered through a researcher designed postal questionnaire and semi-structured teacher interviews. Both qualitative and quantitative data gathering methods within qualitative research were applied. Whereas qualitative data provide breadth and depth, numerical data can give a more complete picture of the phenomena under study (Blaikie, 2000; Bryman, 2001; Merriam, 1998; Patton, 2002).

The interview questions were designed to further explore teachers’ views about investigation. Questions were divided into four sections with background information on the philosophy of science teaching, teaching and learning, assessment, and motivation. The first set of questions was to encourage teachers to share background information and then to talk about their philosophy of science teaching. The questions about teaching and learning investigation were underpinned by the substantial international literature. It is the results of their philosophy of science teaching, and teaching and learning science investigation that are reported in this paper. Teacher practice and assessment of investigation have been reported elsewhere (Moeed, 2010; Moeed & Hall, 2011). Both the questionnaire and the interview questions were pilot tested with teachers out of the region who were non participants.

Teacher Survey

A survey of all (165) year 11 science teachers in the Wellington region was carried out. This anonymous postal questionnaire had a response rate of 61% where 101 teachers responded. Participants in the regional survey came from a coeducational school (64%), boys’ schools (17%) and girls’ schools (19%). The teaching experience of participants ranged from under five years to

over 16 years, 40% having fewer than five years experience, 29% more than 16 years, 14% between 6 and 10 years, and 17% between 11 and 15 years. One respondent did not indicate their teaching experience. In terms of socio-economic setting of the schools, participants were from high (46%), medium (33%), and low (21%) socio-economic communities. More participants (50%) came from large schools (student numbers 800+) than medium size (500–799 students) schools (32%) or from small schools (fewer than 500 students -19%). Sixty-one teachers were female and 40 male.

Analysing the results of the survey, the responses were coded using five themes—open-ended investigation, scientific method, fair testing, experiment, and skill development—which were then aligned and triangulated with current understanding of the literature, the curriculum, and the criteria for assessment. As there were overlapping features in each category, the defining characteristic for each code was identified. For example, the code for open-ended investigation required consideration of a phenomenon or concept which included the suggestion of an iterative process. The purpose was to create a robust framework for analysis (Appendix 1). Applying the framework, the question about teacher understanding was coded by two researchers. These two researchers applied different codes for ‘scientific method’ and ‘fair testing’, so using the framework it was agreed that the code for scientific method should include hypothesis and fair testing, and control of variables. Thus no other coding changes were required.

Teacher interviews

All ten teachers who taught a year 11 science class in a typical coeducational, medium size school situated in a middle socio-economic community were interviewed through a semi-structured interview. The decision to interview teachers was made in order to gather rich data that allowed the researcher to explore points of interest in some detail which is not possible in a survey (Abrahams & Millar, 2008). Of the 10 teachers interviewed, nine were New Zealand trained and one overseas trained teacher who had completed a refresher course in New Zealand. Five were females and five males. Among them, the minimum teaching experience was two years and the maximum 32 years. They were of mixed ethnicities but predominantly European New Zealanders. All had taught their specialist science subjects in the past except for one who was a trained chemistry and biology teacher but who taught physics, a subject in which she was also confident about the content knowledge. Five were biologists, three chemists and two were physicists. Half of the teachers interviewed had taught before the introduction of the NCEA. The sample of teachers interviewed was reflective of the regional science teachers surveyed.

Results

Results of the regional science teachers’ survey

An open-ended question was asked inviting the teachers to describe the features of an investigation that they perceived best supported their students’ learning:

In your view, what features make up a science investigation that would best support Year 11 student learning? (*Do not limit yourself to AS 1.1*)

Up to three comments were coded for each respondent. Not all teachers gave ‘features of investigation’; only 82 (39%) of the responses were investigation related. Teaching-related and student-related features were respectively identified in 22% and 21% of all responses. Student-

related responses included supporting learning through responding to student interest, for example “it helps because students are really interested and love doing things” (Q 036). A smaller number of teachers said that “doing hands-on practicals” (Q 075) facilitated the development of student skills such as lighting a Bunsen burner or using a measuring cylinder. Teacher related responses described the management of materials, setting up investigation, and issues of time and resources. A smaller percentage (12%) of responses related to assessment and curriculum. They included teaching science investigation because they are assessed for NCEA¹: “students will be doing AS1.1 so they need to learn to get at least Achieved and I try to prepare them. My class are not very able” (Q 082). A few (8) indicated that students needed to learn it because it was a curriculum requirement (4%) (See Table 1).

Table 1. Teachers’ responses about features of science investigation that in their view best supported student learning (101 teachers responded)

Features best supporting learning	Teacher responses (n=209)	
	no.	%
Investigation related	82	39
Teacher and teaching related	45	22
Student related	44	22
Assessment related	24	12
Curriculum related	8	4
Other	6	3

Features of investigation identified most often (39% of responses) related to the nature of investigation. A framework underpinned by the characteristics of investigation, scientific method, fair testing and experiment was created and used to analyse the survey responses and teachers’ interviews (Appendix 1). Both the questionnaire data and the interview transcripts were coded using this framework and were checked three times for accuracy and consistency. Quotations are attributed to the respondent through placing a number in brackets at the end of the quote for example (Q 21). Investigation-related responses indicated four different ways of supporting the learning of investigation and four correspondingly different ways of understanding investigation. The results are presented in Table 2.

Table 2. Features of science investigation identified by 39% of teacher responses

Features best supporting learning	Teacher responses	
	no.	%
Investigation related	82	39
Experiment	35	43
Scientific Method	24	29
Fair testing	17	21
Topic-based Investigation	6	7
Skills	0	0
	82	100

The most sophisticated responses, which were also the most fully articulated, supported learning that began with consideration of a topic or phenomenon, followed by identification of a question or hypothesis and the development and carrying out of an investigative process to respond to the question. One example described:

Observing phenomena and asking questions about them; Developing predictions (hypotheses) from observations; Identifying key variables and controlling relevant factors to validly establish a fair test; Carrying out a plan developed by investigator; Collecting raw data by measurement and observation; Processing of data—ranking, means, graphs—to identify trends or patterns; Relating observed patterns to the initial hypothesis and explaining it in terms of scientific ideas/principles; Critiquing and constructively analysing own experimental practices. (Q 060)

Just six of the 82 investigation-related responses (7%) gave this ‘topic-based’ or ‘phenomenon-based’ understanding of investigation. The other three response categories may be seen to provide parts of this topic-based understanding. Almost 30% of investigation-related responses described learning of investigation as best supported through ‘the scientific method’ which was described as a process starting with a given aim, purpose, hypothesis or prediction and proceeding through planning, data collection, analysis, and interpretation, to a conclusion. Responses that explicitly identified scientific method or included a description of most of these stages, for example “[a]n investigation that allows the student to demonstrate knowledge of scientific method ... [and] work confidently and independently using skills of planning, carrying out, recording, processing, analysing etc” (Q 033), were identified in this category.

Twenty-one percent of investigation-related responses identified fair testing as the best way to support investigation. These responses explicitly named fair testing or identified manipulation or control of variables or a concern with validity and reliability, for example “fair test ... valid, reliable” (Q 071). An immediate focus on data collection, or hands-on or practical activities as the best way to support learning of investigation occurred in 43% of the investigation-related responses. These responses were categorised as ‘experiment’, for example “measure/collect data” (Q 042) and “experiments to help grasp concepts” (Q 048). Most investigation-related responses were coded in one category, though occasionally two were coded, for example scientific method and fair testing.

Interview results

The interviews allowed the opportunity to probe and gain a better understanding of teacher thinking. All names that appear are pseudonyms and numbers indicate the number of teachers who gave a particular response. Science investigation was seen by most teachers as children ‘doing’ science to find out, seeing theory proven “so they can believe it”, learning skills and applying them in new contexts, and in students’ everyday lives (n=9). More specifically, Beth thought it was a logical process that could be applied beyond the science classroom. She also said she made sure that students thought about the reliability of their results. Lillian said that there was a place for science investigation, and that investigation should be done as a way of testing the theory learnt. She emphasised the need to teach students to investigate; she modelled the process in her teaching and then extended student investigation by getting them to apply what they had learnt. The following quotation illustrates how she got her students to investigate the reactivity of several metals.

We did magnesium and acid, magnesium and water, magnesium and oxygen. It took two periods. And they looked at all of those and by the end of two periods they could tell me all of the information for anything. They could tell me what they were going to make (the product of the reaction). And then I said well okay if magnesium does this, what do you think copper will do? And then I said here you've got four metals. You go and decide which one is the most reactive, which one is the next and so on. And that was their brief – go and sort them out, I'll be helping you do it. So I'd given them some information, I'd said okay go and work it out. And I think that's how investigations have to be used rather than, finding things in the dark. (Lillian)

Students start from knowing the process as it has been modelled for them, and then they find out. Lillian saw this modelling as crucial to teaching students to investigate. In Mike's opinion, investigation is what science is all about. Tanya, Mandy, and Sandra believed that learning to do science was really important and was the way all science should be taught. Tony said he would like to do more investigations but found it a real challenge to get his students to take anything seriously.

Further probing through asking the teachers what their goals were for student learning through science investigation provided some detail that was missing in the teacher responses for the first question. When talking about the goals for student learning through investigation, all teachers (n=10) focused on the fair testing type of investigation that is assessed in AS1.1. Although most talked about the importance of learning skills, four saw teaching students the vocabulary for them to do well in the internal assessment as a key goal. Two teachers believed that this should be done before year 11. Stella said:

Start the children off in year 9. Teach them the vocabulary used as far back as that. Knowing that they need to back up their results with evidence and then discuss them. (Stella)

Beth said she was concerned about the fair testing type of investigation she was teaching and was dissatisfied with doing investigation that did not lead to new learning. She did more investigation in chemistry than other content areas, but said she was not sure what students learnt from it. Her explanation was that she was getting the students to do investigations that had such obvious answers that she could not expect them to want to do them. She talked about "Excellence kids" getting involved in them. When probed about this statement she explained that for those students, they could see beyond the obvious results and could think about the energy changes involved in a car rolling down a ramp, and demonstrate the conceptual understanding beyond the fact that as you increase the slope of the ramp the car will travel further.

Some teachers (n=4) talked about how learning the scientific method, learning how to carry out a fair test type of investigation, students could see theory being applied. Len's response covered aspects of investigation:

Science is fun and by doing they learn about gathering data. They can have fun, carry out the investigation, collect data and be able to talk about it, about what they have gathered. And from that use the principles of science to help explain a little bit clearer. (Len)

Overall, the goal was to teach a fair testing type of investigation and learning skills, and there was a concern that students were doing investigation for which they already knew the answer. Further insight was gained through asking teachers' views about student learning through investigation. Teachers (n=10) said that students learn the skills of planning, gathering information, processing and interpreting information, and reporting it, which are those skills identified in the assessment guide for AS1.1. They said that students need to learn these skills and also know what they will need to do for assessment. Teachers (n=6) said they teach students the vocabulary they need to use for the assessed investigation. Four teachers mentioned teaching what students need to write to get an Achieved, Merit, or Excellence grade. Two teachers said they wanted the students to know that science is real and that we investigate all the time. Another teacher described in some detail what he wanted his students to learn through investigation:

The ability to plan, to complete the fair test thoroughly, understanding of the variables and what they have to measure, what they have to keep fair, appropriate handling of the equipment so that they are doing their measuring accurately and safely and cooperating with each other, it has to be said, was a factor as well of course and then analysing the data on a straightforward interpretation level, plotting a graph without making too many blunders along the way, writing a conclusion which links what they have learnt with the science behind it and evaluating, we also ask them to evaluate, you know, what went wrong, what can we do next time and, I think that's probably about it. (John)

The details offered by the teacher indicated that they wanted the students to be able to do what was required of them to carry out a fair testing type of investigation.

Discussion

Teachers saw science investigation as a sequence of steps. Regional year 11 science teachers' responses to the questionnaire identified features of science investigation that best supported students' learning to include, most often, conducting experiments or carrying out the scientific method, less often undertaking fair testing, and rarely topic-based investigation. The common aspect of each of these responses was the inclusion of a sequence of focussing, planning, data gathering, processing, interpreting, and reporting, in part or in its entirety. During the study school science teachers' interviews a further insight was gained into teachers' understanding of science investigation which showed that some teachers were able to reconcile different perspectives on science investigation.

Most regional science teacher responses from the questionnaire described experiments as trying things out, gathering information or interpreting it, and in the interviews teachers used the term experiments for any practical work done in science. This is consistent with McNally's (2006) and Wellington's (1998) findings that teachers often did not understand clearly what they meant by experiments. The results of this study do not suggest that generally "students can understand the characteristics of a scientific experiment" as required by *Science in the New Zealand Curriculum* Nature of Science, Achievement Objective 1 (Ministry of Education, 1993, p. 36). Teachers themselves may not have a clear understanding of what an experiment is—*Science in the New Zealand Curriculum* does not define an experiment.

Some teachers interviewed considered experiments as an activity to confirm a theory; for example, when a piece of magnesium ribbon is burnt the theory of oxidation would be confirmed

(Abrahams & Millar, 2008). Scientific method, as described by the regional teachers, involved students starting with a hypothesis, writing a method, gathering information, writing results, and coming to a conclusion. The emphasis is on a linear and sequential process. According to Tytler (2007), emphasising the scientific method leads to thinking that science investigation is a linear process where steps are followed to get the right answer. However, Millar (2004) and Hodson (1993) argue that there is no one scientific method and that scientists follow many different methods when investigating.

According to Windschitl et al. (2007, p. 942), as implemented in school classrooms in the US, “the scientific method [includes] ... testing of predictions rather than ideas” and suggests that models could be used for testing ideas. Windschitl et al.’s key criticism of the scientific method is that it is a procedure and “not a way of thinking” (2007, p. 947) and that in school science students may be able to follow the process and complete the investigation without engaging with the underlying science ideas or being challenged to think and reason scientifically.

The use of scientific method persists in year 11 science as evident in the regional science teachers’ responses that identified the scientific method as a feature of investigation. The reason for this may be as suggested by Lunetta et al. (2007) who attributed the persistent use of the scientific method to a lack of confidence and limited understanding of the science ideas on the part of the teacher. Windschitl et al. (2007) argued that scientific method enables teachers to manage practical work in overcrowded classrooms. It could be that the teachers find it useful as a framework for reporting the findings of the investigation as suggested by Mahootian and Eastman (2008), although there was no evidence found to support this theory in the present research.

Fair testing was identified in the regional teachers’ responses, and some teachers interviewed described investigation as fair testing. These teachers described fair testing as part or all of a linear process of planning, gathering, processing and interpreting data and reporting information. Critically, it includes identifying and controlling of variables. This understanding of fair testing investigation is frequently referred to in *Science in the New Zealand Curriculum* and is the type of investigation used for assessment through the NCEA’s AS1.1.

In contrast to the regional teachers’ predominant views, only a few teachers cited a problem-based or topic-based open-ended process as a feature of investigation that best supported student learning and thus had a contemporary view of investigation. However, two teachers when probed during interviews clearly distinguished their understanding of investigation from the fair testing they taught for NCEA assessment. They described investigation as an open-ended and iterative process. This contemporary view has been theorised by Millar (2004) and in essence, involves identifying a problem or a question that needs to be addressed, as well as planning an investigation, experimenting to evaluate the process, gathering, processing and interpreting information, and reporting results. Millar (2010) says students may have some choice in selecting the question but this is not a defining feature of science investigation. In his view, critical evaluation of both process and findings is an essential component of an investigation. It is not linear and does not always lead to the right answer. Roberts (2009) in the United Kingdom, Tytler (2007) in Australia, and Hume and Coll (2008) in New Zealand are in agreement with this view.

Teachers’ understandings of investigation involve the processes of planning, data gathering, processing and interpreting, and reporting in part or collectively. This may be indicative of the influence of the curriculum, though the curriculum statement’s concern with initial focussing and problem-solving is far less evident in teachers’ views. Teachers’ understandings have more to do with the NCEA approach where the investigation begins with a purpose or aim and neglects concern with focussing and problem-solving. The NCEA approach

requires the manipulation and control of a variable and is limited to a fair testing type of investigation. However, the most common term used by teachers to express features of investigation was the traditional experiment and scientific method, which has a low profile in the curriculum and assessment documents. Despite this traditional understanding, investigation is mostly taught as a fair testing type of investigation.

Conclusions

- Year 11 science teachers understand science investigation as a linear and sequential process. They described features of science investigation that supported student learning as experiments, scientific method, and fair testing. Very few science teachers had a contemporary, open-ended view of science investigation.
- Teachers identified “experiment” as the “doing” of science or “practical work”, whether it was within an investigation or in an activity by itself.
- The assessment of science investigation as fair testing for AS1.1 in year 11 has promoted a narrow view of science investigation as linear and sequential, and leading to one “correct” answer.

Limitations of the Research

It is accepted that results reported here are drawn from one section of the country’s teachers and based on findings that emerged from a larger study reported earlier (Author, 2010). Deeper insights may have been possible if a national teacher survey was carried out; perhaps focus group interviews of regional teachers would have enriched the data collected through questionnaires.

Recommendations for Further Research

The findings illuminate an interesting and critical point that if teachers have limited understanding of the phenomenon of investigation, then students are also likely to develop a limited understanding. A more in-depth study encompassing teachers’ beliefs, orientation to teaching and teacher understanding of investigation is required as a matter of urgency.

It was unclear whether teachers did understand what an investigation was as the requirement of assessment has made them focus so much on the assessed investigation that they have begun to see investigation mostly as fair testing. Perhaps it is time to rethink assessment of investigation in its present form. Research from the UK has highlighted that assessment of science investigation in mass education is problematic, and issues have been raised with respect to reliability and validity of such assessment (Moeed & Hall, 2011; Gott & Duggan, 2002; Millar, 2004; Roberts & Gott, 2004a). With two in-depth New Zealand case studies (Moeed & Hall, 2011; Hume & Coll, 2008) having highlighted that not only is the assessment of investigation leading to students developing a narrow view of investigation but also revealing that teachers may well be looking at investigation for assessment, it is timely to explore other ways of assessment of practical work.

In New Zealand, with the implementation of the new curriculum (Ministry of Education, 2007) that places the nature of science and investigation within it in a cameo position, we need to know what teachers understand science investigation to be if they are expected to teach it. To

enhance practice, teachers need to be supported through professional development in ways that allow them to meet more effectively the goals set out for science education in New Zealand. At a policy level it is not just the secondary teachers that require better understanding of investigation but there is a need to build capacity through pre-service teacher education.

Finally, the *Science in the New Zealand Curriculum* was underpinned by the constructivist theory of learning. Pedagogy based on constructivism requires an interaction between teacher and learner that includes eliciting of prior knowledge, exploration, and reflection. There was little evidence that teachers applied constructivist pedagogical approaches. Perhaps with the implementation of the new curriculum there is a need for any related professional development to help teachers understand the theory that underpins the document.

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Appendix 1. Framework for analysing science investigation that best supports student learning

Practical activity	Features	Theoretically based definitions by:
Open-ended investigation	<ul style="list-style-type: none"> • Consideration of a phenomenon or concept • Identify question/hypothesis • Develop a plan • Carry out investigation (gather data) • Process, interpret and seek patterns • Explain results in terms of ideas /principles/evidence • Critique, constructive analysis • Suggest an iterative process 	Millar (2010) Roberts (2009) Tytler (2007) <i>Science in the New Zealand Curriculum</i> MoE (1993)
Scientific method	<ul style="list-style-type: none"> • Identify aim/purpose/hypothesis/prediction • Plan, gather data • Analyse and interpret • Write conclusion Could be a “recipe” to follow Leads to an expected result	Bradley (2005) Hipkins et al. (2002)
Fair testing	<ul style="list-style-type: none"> • Start with a scenario • Identify a question • Plan • Manipulation of variable/Control variable • Awareness of reliability Hands-on engagement	Watson, Goldsworthy and Wood-Robinson (1999) <i>Science in the New Zealand Curriculum</i> MoE (1993) NZQA (2004)
Experiment	<ul style="list-style-type: none"> • Intervention Either within an investigation or trying out a process by itself	Wellington (1998) Abrahams and Millar (2008)
Skill development	<ul style="list-style-type: none"> • Identified skill to be acquired e.g. lighting the Bunsen burner/ measurement of liquid/temperature • Process skills of planning, data gathering, processing and interpreting, and reporting 	<i>Science in the New Zealand Curriculum</i> MoE (1993)

Note: in each category the underlined aspect was the defining idea for each category.